U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-279 078

Performance Testing of Selected Inland Oil Spill Control Equipment

Mason and Hanger-Silas Mason Co, Inc, Leonardo, N J

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

Aug 77

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-150	2.	3. RECIPIENT'S ACCESSION NO. PB279078
4. TITLE AND SUBTITLE PERFORMANCE TESTING OF SELECTED INLAND OIL SPILL CONTROL EQUIPMENT		5. REPORT DATE August 1977 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William E. McCracken		8. PERFORMING ORGANIZATION REPORT NO. MHSM-LNJ-01
9. PERFORMING ORGANIZATION NAME AND ADDRESS Mason & Hanger-Silas Mason Co., Inc. P.O. Box 117 Leonardo, NJ 07737		10. PROGRAM ELEMENT NO. 1BB041 11. CONTRACT/GRANT NO. 68-03-0490
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory- Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final April 1975-March 1976 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

Supplements a professional movie of the same title.

16. ABSTRACT

Standardized performance tests were conducted at the Environmental Protection Agency's test facility, OHMSETT, with various off-the-shelf inland oil-spill control and clean-up devices. Operability limits were defined and then quantified via testing for eight boom systems and eight stationary skimmers. This information allows those concerned with spill control to match the proper equipment with the existing environmental conditions (wave characteristics, current, and oil properties) associated with an oil spill in inland waters.

Boom systems were tested in the catenary (U) configuration for oil collection capabilities and in the diversionary (J) configuration for fast current oil diversion capabilities. Booms were first tested for stability capabilities over a wide range of wave conditions without oil and then in wave conditions within their operational stability limits with oil. Booms and stationary skimmers were tested in the same wave conditions and oils. Two test oils were used--No. 2 Fuel Oil and Sunvis 75 Lubrication Oil (without additives).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Pollution Performance Tests		13B

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 125
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A06-A01

EPA Form 2220-1 (9-73)

* U.S. GOVERNMENT PRINTING OFFICE : 1977 0-241-037/58

PB 279 078

EPA-600/2-77-150
August 1977

Environmental Protection Technology Series

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EPA-600/2-77-150
August 1977

PERFORMANCE TESTING OF SELECTED INLAND OIL SPILL CONTROL EQUIPMENT

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes performance testing of a total of sixteen commercial, off-the-shelf inland oil spill control and cleanup devices under a variety of controlled conditions. Based on these results, a number of operating techniques are recommended to ensure maximum performance. The methods, results, and techniques described are of interest to those interested in specifying, using or testing such equipment. Further information may be obtained through the Resource Extraction & Handling Division, Oil & Hazardous Materials Spills Branch in Edison, New Jersey.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Standardized performance tests were conducted at the U.S. Environmental Protection Agency's test facility OHMSETT with various off-the-shelf inland oil spill control and clean-up devices. Operability limits were defined and then quantified via testing for eight boom systems and eight stationary skimmers. This information allows those concerned with spill control to match the proper equipment with the existing environmental conditions (wave characteristics, current, and oil properties) associated with an oil spill in their inland waters.

Boom systems were tested in the catenary (U) configuration for oil collection capabilities and in the diversionary (J) configuration for fast-current oil diversion capabilities. Booms were first tested for stability capabilities over a wide range of wave conditions without oil and then with oil in wave conditions within their operational stability limits. Booms and stationary skimmers were tested in the same wave conditions and oils. Two test oils were used--No. 2 Fuel Oil and Sunvis 75 Lubrication Oil (without additives).

Operating techniques are recommended to ensure maximum performance of skimmer systems (especially in very viscous oil) and booms deployed in both containment and diversionary modes. The parachute mooring technique is described for setting up a diversionary boom system. Proper use of boom and connectors and universal bridles is described for operational stability at higher currents.

A professional movie, entitled "Performance Testing of Selected Oil Spill Control Equipment for Inland Use", was produced in conjunction with this test project.

This report was submitted in partial fulfillment of Job Order No. 6 by Mason & Hanger-Silas Mason Co., Inc., Leonardo, New Jersey, under the sponsorship of the United States Environmental Protection Agency, Contract No. 68-03-0490. This report covers the period April 17, 1975 to June 16, 1975; work was completed as of March 15, 1976.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

cm --centimeter
cm^2/s --centimeters squared/sec
cSt --centistokes
m^3 --cubic meters
m^3/min --cubic meters per minute
m^3/s --cubic meters per second
CPM --cycles per minute
ft --feet
gal --gallons
gpm --gallons per minute
H/L --height to length steepness ratio
in --inch
IERL-Ci --Industrial Environmental Research Laboratory-Cincinnati, Ohio
I.M.E. --Industrial and Municipal Engineering
I.R. --infrared
kg --kilograms
kg/m --kilograms per meter
kt --knot
m --meter
m/min --meters per minute
m/s --meters per second
m^2/s --meters squared per second
mm --millimeters
mV/m/s --millivolts per meter per second
OHMSETT --Oil and Hazardous Materials Simulated Environmental Test Tank
p.p.t. --parts per thousand
% --percent
PACE --Petroleum Association for Conservation of the Canadian Environment
lbs --pounds
lbs/ft --pounds per foot
SSU --Saybolt Universal Seconds
sec, s --seconds
ft^2 --square feet
m^2 --square meters
V/m/s --volts per meter per second

SYMBOLS

U --Catenary boom configuration

SYMBOLS (continued)

V_c --critical velocity

J --Diversionary configuration
' --feet
" --inches
∞ --infinity
± --plus or minus next amount shown

LIST OF EQUIPMENT TESTED

BOOMS

1 Clean Water, Inc., HARBOUR BOOM

2 Coastal Services Coastal Oil Boom

3 Acme Products Company OK Corral Containment Boom

4 B.F. Goodrich SEA Products 18 PFX Permafloat Sea Boom

5 Slickbar, Inc., Mark VI Boom

6 Kepner Plastics Fabricators, Inc., Sea Curtain

7 PACE (Petroleum Association for Conservation of the Canadian Environment) Oil Boom

8 Whittaker Corporation Expandi-Boom

STATIONARY SKIMMERS

1 Slickbar, Inc. - 2.5 cm (1 in) Rigid Manta Ray (No. 1)

2 Slickbar, Inc. - 2.5 cm (1 in) Flexible Manta Ray (No. 2)

3 Slickbar, Inc. - 1.3 cm (0.5 in) Flexible Manta Ray (No. 3)

4 Slickbar, Inc. - Aluminum Skimmer (No. 4)

5 Acme Products Company - Floating Saucer SK-39T

6 British Petroleum Company, Ltd., Komara Miniskimmer

7 Coastal Services - Slurp

8 Industrial and Municipal Engineering Company (I.M.E.) - Swiss OELA III

ACKNOWLEDGMENTS

This report presents the results of the OHMSETT testing of manufacturer supplied equipment. The cooperation of all participating manufacturers is sincerely appreciated.

Mr. F.J. Freestone is the Project Officer of OHMSETT which is owned by the U.S. Environmental Protection Agency. Messrs. F.J. Freestone and J.S. Dorrler jointly served as the Project Officers for this project and provided valuable assistance.

Mason & Hanger-Silas Mason Co., Inc. is the operating contractor for OHMSETT. Mr. R.A. Ackerman, Manager, Mr. Gary Smith, chemist, and Mr. Michael Johnson, test director, provided valuable guidance and suggestions throughout the test project which is acknowledged with sincere thanks. Also, Mr. S.H. Schwartz, engineering aide, assisted greatly in the preparation of this report including graphics and tables for which we express sincere thanks. The effort of all the technicians involved in the testing program is greatly appreciated.

Funds for this project were provided by the Edison, N.J., office of the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnnati, Ohio.

SECTION 1

INTRODUCTION AND OBJECTIVES

BACKGROUND

Numerous oil spill control and clean-up systems exist today that have application in the inland waterways. Some manufacturers supply both booms and skimmers as a complete, integrated system for oil removal, while others supply only one or the other. A definite need has existed for a test facility to evaluate these systems on an equal basis to determine their operable ranges and to determine the best combination of devices to meet the immediate needs of the inland environments. Reliable performance data is usually not available and performance has been estimated either by unrepeatable, uncontrolled real world tests or by extrapolation (References 1 and 2).

OHMSETT is a test facility where performance testing and evaluation of full-scale and prototype equipment can be conducted. (For details see Appendix A). Several reasons for conducting oil spill control equipment performance tests in a hydrodynamically controlled environment, such as OHMSETT are:

- They cannot be legally conducted on the open waterways, without specific governmental approval.
- Ability to establish simulated hydrodynamic-environmental conditions.
- Ability to establish simulated oil (or other hazardous material) spill conditions on open waterways.
- Ability to repeat the test conditions and results to establish a statistical format.

All of the above reasons lead to the ultimate goal of performing standardized tests. These are necessary to quantify the performance characteristics of equipment with respect to design specifications and other similar equipment. Ultimately, the results obtained will allow the user of the equipment to match the proper equipment with specific environmental conditions.

SCOPE

The purpose of this project was to test and evaluate commercially available inland oil spill control equipment--booms and skimmers. Tests were conducted in a standardized manner to produce results such that field users would be able to objectively judge the relative merits of various devices and combinations of equipment used in inland oil spill conditions. Thus, test conditions and procedures were designed to correspond to the typical inland waterway field use requirements. For wave conditions, characterizations are given in References 3 and 4.

Booms and skimmers that represented a cross-section of the commercial market were solicited for testing on a consignment basis. Booms were restricted to a maximum of 0.61 m (24 in) skirt and 61.0 m (200 ft) in length. Skimmers were restricted to being stationary type, operable in 2.4 m (8 ft) of water, and of size and weight to be reasonably managed by two men deploying and operating them. The number of pieces of equipment to be tested was limited by the project funds and test time available. Eight booms and eight skimmers were solicited and tested.

SECTION 2

CONCLUSIONS

The following conclusions are based on standardized testing of various off-the-shelf inland oil spill control and clean-up skimmers and barriers. The testing was undertaken to relate various salient design features to performance in various waves and currents representative of those found in inland waterways. Direct comparison of booms and skimmers was avoided. Each boom and skimmer system was recognized as having its place of application in the wide range of environmental conditions that exist on the inland waterways. The tests conducted at OHMSETT defined the range of waves and currents under which each type of system would perform. Only performance tests were conducted.

For boom systems, the relationship between net buoyancy, skirt draft, towing arrangement, and maximum tow speeds (currents) relative to waves are:

1. Catenary Boom Stability above 0.81 m/s (1.6 knot) current and 0.61 m (2 ft) wave (.067 steepness ratio, H/L)
   a. Net Buoyancy 44.6 kg/m (30 lbs per lineal foot)
   b. Skirt Draft 0.3 m (1.0 ft)
   c. Towing Arrangement...tension concentrated near bottom
2. Catenary Boom Containment at 0.51 m/s (1.0 kt) current and 0.61 m (2 ft) wave (.067 H/L)
   a. Net Buoyancy 10.4 to 29.8 kg/m (7 to 20 lbs per lineal foot)
   b. Skirt Draft 0.15 to 0.30 m (0.5 to 1.0 ft)
   c. Towing Arrangement...tension concentrated near bottom
3. Diversionary Boom Stability above 0.81 m/s (1.6 kt) current and 0.61 m (2 ft) wave (.067 H/L)
   a. Net Buoyancy 37.2 kg/m (25 lbs per lineal ft)
   b. Skirt Draft 0.46 m (1.5 ft)
   c. Towing Arrangement...tension concentrated near bottom
4. Diversionary Boom Diversion above 0.56 m/s (1.1 kt) current and 0.61 m (2 ft) wave (.067 H/L)
   a. Net Buoyancy 37.2 kg/m (25 lbs per lineal foot)
   b. Skirt Draft 0.46 m (1.5 ft)

c. Towing Arrangement...tension concentrated near bottom

All boom tests, excepting one, were conducted with a high viscosity lubrication grade oil. To illustrate the effect of a low viscosity oil on boom performance, one boom system was tested with both the lubrication oil and No. 2 fuel oil. The results indicated a slight decrease in the critical tow speed (no oil loss speed) of 0.07 m/s (0.15 kt).

Considering the eight boom systems as representing the current technology for spill control systems on inland waterways, the optimum performance for all of the booms at the various conditions was:

- Catenary Configuration (Stability Performance): Maximum Stable Tow Speed ranged from 0.25 m/s (0.5 kt) at a wave steepness ratio of 0.111 to 1.27 m/s (2.5 kt) at calm water conditions.

- Catenary Configuration (Performance with Oil): Maximum "No Oil Loss" Tow Speed ranged from 0.25 m/s (0.5 kt) at a wave steepness ratio of 0.111 to 0.46 m/s (0.9 kt) at calm water conditions.

- Diversionary Configuration (Stability Performance): Maximum Stable Tow Speed ranged from 0.25 m/s (0.5 kt) at a wave steepness ratio of 0.111 to 1.02 m/s (2.0 kt) at calm water conditions.

- Diversionary Configuration (Performance with Oil): Maximum "No Oil Loss" Tow Speed ranged from 0.25 m/s (0.5 kt) at a wave steepness ratio of 0.111 to 0.81 m/s (1.6 kt) at calm water conditions.

The diversionary capability of each boom system to divert oil from the fast current regions on an inland waterway to the slow current regions where oil collection (i.e. skimmers) is initiated was determined. For currents greater than 0.51 m/s (1 kt), with the boom in the catenary configuration, the tank tests indicated that the oil could not be contained. In that most inland waterways have surface currents in excess of 0.51 m/s (1 kt), diversionary boom techniques are most successful. From vectorial analysis of the forces exerted on a boom by the current, the theoretical benefit of angling a boom relative to the current can be easily calculated. However, deploying a flexible boom to maintain a constant angle along its entire length is impossible. Thus, parachute mooring lines and other techniques are used to maintain the current directed perpendicularly against the boom below the 0.51 m/s (1 kt) limit (Figure 9).

In that booms and skimmers must operate in the same environmental conditions, the skimmers were tested with the same wave conditions as the booms. Two different oils were used to test skimmer performance and their dependence on oil viscosity. The oil slick thickness was controlled at 2.54 cm (1 in), which represents actual inland-use situations where the oil slick is thickened either by containment in a boom moving against the current, or by diversion along a boom angled against the current.

In general, the skimmer's performance was affected by oil viscosity. The rotating disc type skimmer performance strongly increased with viscosity.

The self-adjusting weir and floating suction head registered a slight increase with viscosity, while the adjustable weir performance remained unaffected.

Also, the oil recovery capacity was very much dependent on the other components in the skimming system--the connection hose (diameter and length), the type of pump (diaphragm or axial flow) and the discharge hose (diameter and length). For the viscous oils, hose diameters and lengths, 7.6 cm (3 in) and 15.2 m (50 ft) worked best for the pumps involved. Also, the diaphragm pumps perform much better in viscous oils than axial flow or centrifugal pumps.

There was no clear correlation of skimmer performance and wave conditions for the waves observed. In some cases, there seemed to be a slight improvement and in other cases a slight decrease in performance with certain waves. In general, these differences were small enough to be explained by the inaccuracies of test measurement.

SECTION 3

RECOMMENDATIONS

Additional tests should be conducted with other oils and/or chemicals which cover a wide spectrum of critical properties (i.e. viscosity, specific gravity and interfacial tension). Theoretical predictions of "No Loss" speeds should be correlated with measured speeds for the catenary and diversionary boom configurations. These tests should also include random and breaking waves (e.g. harbor chop).

In that the boom encounter angle with respect to current (diversionary configuration) was held constant for each boom system, the effect of varying this angle (i.e. 0 → 90) for one boom at each wave condition would be of considerable interest. The potential user of this equipment would then have experimental data which could be used to define the angles at which the boom should be deployed for "No Oil Loss" once the current and wave conditions are known. Also, for the industrial facilities located at a fixed point on an inland waterway, the boom design features necessary for controlling potential spills could be determined and deployment techniques well defined.

Skimmer systems are inherently viscosity dependent. Even if the skimmer head is viscosity independent (e.g. weir types), the connecting hose, pump and discharge hose are viscosity dependent. Thus, when testing skimmers, the entire system must be well defined (i.e. hose diameter, pump capability). As recommended for the booms, the skimmers should be tested in random breaking waves, such as are found in harbors and inlets.

Some underwater films were taken during this test project, which documented the oil entrainment phenomena that occurred when testing booms in both the containment and diversion modes. In order to fully understand these phenomena, further testing should be designed and conducted to correlate the best available theoretical predictions with test data both measured and clearly photographed. Underwater photography would need to be of high resolution for documenting droplet size and interfacial waves and turbulence.

SECTION 4

FACILITY AND TEST APPARATUS DECRIPTION

OHMSETT DESCRIPTION

The OHMSETT facility is located in Leonardo, New Jersey, at the Naval Weapons Station Earle. (For details see Appendix A). The facility was built specifically for the testing of oil and hazardous materials control equipment. Waves can be generated up to 0.9 m (3 ft) high and 45.7 m (150 ft) long and current simulated with a towable bridge up to 3.1 m/s (6 kt). The tank can be filled with either fresh or sea water. The sea water comes from the Sandy Hook Bay (salinity 20 p.p.t.) and was used during these tests.

DESCRIPTION OF MODIFICATIONS TO OHMSETT

In order to adequately test the recovery systems it was necessary to make some modifications. A 1.13 m^3/min (300 gpm) oil distribution system was constructed and installed with a flow meter and other instrumentation. Special nozzles to accomodate the high viscosity oils were installed and calibrated for even flow distribution. Also, a traveling truss was constructed which spanned the tank width and was connected to the tow cables used for the bridge. It functions as an observation deck, a reverse skimming system and a tow-back system when returning to the starting position for the next test. For further details of the modifications refer to Appendix B.

LIST OF EQUIPMENT TESTED

Booms

1 Clean Water, Inc., Harbour Oil Containment Boom

2 Coastal Services Coastal Oil Boom

3 Acme Products Company OK Corral Containment Boom

4 B.F. Goodrich SEA Products 18 PFX Permafloat Sea Boom

5 Slickbar, Inc., Mark VI-A Boom

6 Kepner Plastics Fabricators, Inc., Sea Curtain

7 PACE (Petroleum Association for Conservation of the Canadian Environment) Oil Boom

8 Whittaker Corporation Expandi-Boom

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4 Slickbar, Inc. - Aluminum Skimmer (No. 4)

5 Acme Products Company - Floating Saucer SK-39T

6 British Petroleum Company, Ltd. - Komara Miniskimmer

7 Coastal Services, Inc. - Slurp

8 Industrial and Municipal Engineering Company (IME) - Swiss OELA III

For details of the equipment tested, refer to Appendices C and D.

DESCRIPTION OF MEASUREMENT AND INSTRUMENTATION

The measurement and instrumentation systems used were designed to measure, record and document all of the physical parameters necessary to quantitatively evaluate the performance of the test devices. Instrumentation and measurement of fluid properties, fluid recovery, fluid distribution rate, and tow speeds were as follows:

- Fluid Properties - Samples of materials were collected prior to distribution and after recovery. Laboratory analysis included the following:

Specific Gravity	laboratory hydrometers
Viscosity	shear-type viscosimeter flow-thru orifice viscosimeter
Temperature	laboratory thermometer portable I.R. thermometer
Surface Tension	tensiometer
Interfacial Tension	tensiometer
Percent Water	sample centrifuged with 50%

water
saturated Toluene

- Fluid Recovery - Measuring containers, sizes .06, .19, .38, 1.89 m^3 (15, 50, 100, 500 gallons) were calibrated in gallons per inch.

  These containers are constructed of translucent polyethylene, which allows technicians to detect the oil/water interface and take appropriate measurements. In the event that the thickness of either phase was less than 2.5 cm (1 in), that phase was drawn into 1,000 ml graduated cylinders for more accurate measurement. To ascertain that the oil phase contained minimal dispersed water droplets, centrifuge samples of the oil phase were routinely collected and analyzed. When the water content was more than 2.5%, a water content correction was employed.

  The time required to allow complete settling of the oil phase from the water phase depended upon many factors, including the ambient temperatutes, type of oil used, and the amount of mixing caused by the oil removal mechanism (i.e., pump, belt, etc.). A minimum settling time of 1/2 hour with continuous checks was standard procedure.

- Ambient Conditions were recorded prior to each test and a complete record of environmental conditions was compiled. The following parameters were measured using standard weather instrumentation.

  Air Temperature

  Water Temperature

  Wind Speed

  Wind Direction

  Per Cent Humidity

  Barometric Pressure

- Wave characteristics were routinely checked using a Polaroid camera and stopwatch to measure the height, length, and period of OHMSETT generated waves. Using a grid system superimposed on the east tank wall, technicians observed wave parameters and correlated their findings to the wave generator settings of stroke length and r.p.m.

- Test Fluid Distribution Rates and Total Volume Distributed were measured using positive displacement-type flow meters.

Upon signal from the test director, a predetermined amount of oil was distributed through an air-operated nozzle system in line with the flow meter.

- Tow Speed data was acquired using a DC tachometer mounted on the motor shaft of the bridge drive. The gear ratio provided for 3.28 V/m/s which was reduced by a voltage divider to 0.055 mV/m/s and read by a three segment, one volt digital voltmeter.

SECTION 5

TEST PLAN

Inland waterways represent a wide spectrum of environmental conditions such as various wave conditions, currents and water properties. The application of oil spill control equipment is often unique to each specific situation. It would take years to test the application of equipment in all of the different inland situations from tropical swamps and small streams to the Great Lakes iced over in the winter. Thus, the wave characteristics, currents and oil types were selected to representative of the more typical situations. For more detail on these environmental conditions, see References 3 and 4.

The deployment of booms and skimmers in rivers and estuaries requires special techniques. With the high current in midstream and low current near shore, booms are normally angled against the current to prevent oil loss under the skirt. This is called the diversionary boom configuration and usually requires a special mooring technique to maintain the shape of the barrier. This technique and other deployment techniques are given in References 5 and 6. Booms are usually deployed in the catenary configuration (U-shaped, Figure 1) when oil spillage is to be contained against a current less than 0.51 m/s (1 kt). Once the oil is contained, skimmers and other oil removal devices can be utilized. The test program was designed for diversionary performance (J-shaped, Figure 2) as well as containment performance evaluation.

In that certain design features of the test equipment directly affect performance, commercially available skimmers and booms were selected that incorporated the various design features of interest (e.g. for booms, stiffness affects bridging; for skimmers, pump type affects flow rate). For more detail on design features and their effects on performance, see References 7 through 15. The design features considered in this project were: net buoyancy, skirt draft, and towing arrangement for booms; rotating disc, self-adjusting weir, adjustable weir and floating suction head for skimmer designs. Also, several pump designs were tested: centrifugal, axial flow and diaphragm pumps.

A high viscosity lubricating oil stock was used for most of the tests since its properties represented a medium between very viscous oil (No. 6 and greater) and low viscosity diesel fuel. To ascertain the effect of a low viscosity oil, several selected tests were run with diesel fuel.

Performance criteria for booms was aimed at determining the exact tow speed at which oil began to escape the boom in both the catenary and diversionary modes. First, the boom was tested without oil in various waves to determine its maximum stable-operable tow speed in each configuration. Then, it was tested with oil in those waves where its stable performance range was above 0.25 m/s (0.5 kt) tow speed. This acknowledged the fact that a physical phenomenon (oil entrainment mechanism) exists at the oil/water interface which usually determines the maximum tow speed attainable before losing oil under the boom. Also, the splashing and heaving motion of waves can force oil under the top of the booms at tow speeds well below their stability limits. For more detail on these phenomena see References 16 and 17.

For skimmers, it was recognized that oil recovery rates depended upon the pumping system (including hose dimensions and connectors) as well as the recovery device at the oil/water interface. Thus, the test included various pumps, hoses and connectors. Also, two test fluids were used to measure the viscosity effects--diesel fuel and high viscosity lube oil.

The standard test plan reflects the systematic evaluation of boom and stationary skimmer systems relative to various inland environmental conditions and specific design features. Performance was evaluated on the basis that the establishment of maximum operability limits is paramount to the selection of a system to be employed during a real spill situation. In evaluating these limits, the failure mode was visually determined and photographically documented. Stability testing was performed to evaluate at which surface currents (relative velocities) either boom planing, submarining, or other type failure occurred. In addition, splashover at the boom fluid interface was considered to be stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. These failure modes are listed in Table 1 and shown in Figures 3 through 7.

Testing with oil was then performed to observe and note the critical tow speed of other possible modes of failure.

Table 1. Failure modes.

1. Fluid entrainment into the water column (Figure 3)
    - a. caused by interfacial shear
    - b. caused by inertia effects of large wave action (i.e. gravity waves)
    - c. caused by inertia effects of small interfacial wave action (i.e. capillary waves)
    - d. caused by eddy currents
2. Fluid forced (splashed or heaved) over the boom freeboard (Figure 4)
    - a. breaking waves with sufficient height to heave fluid over boom
    - b. splashing at boom - fluid interface
3. Fluid leakage at the joints of boom section
4. Boom failure relative to stability
    - a. boom planing (Figure 5)
    - b. boom submarining (Figure 6)
    - c. boom oscillating
    - d. boom bridging (Figure 7)
5. Fluid drainage under the boom due to excessive fluid thickening

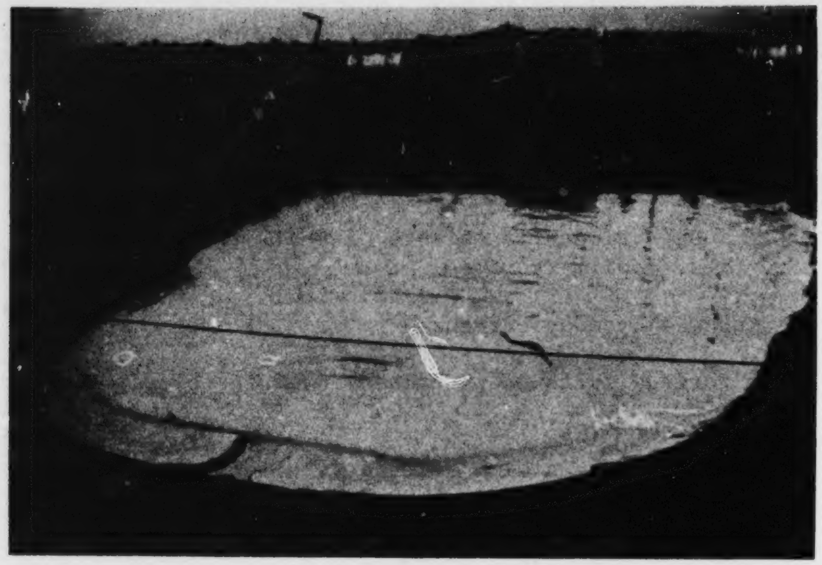

Figure 1. Photograph of catenary configuration.

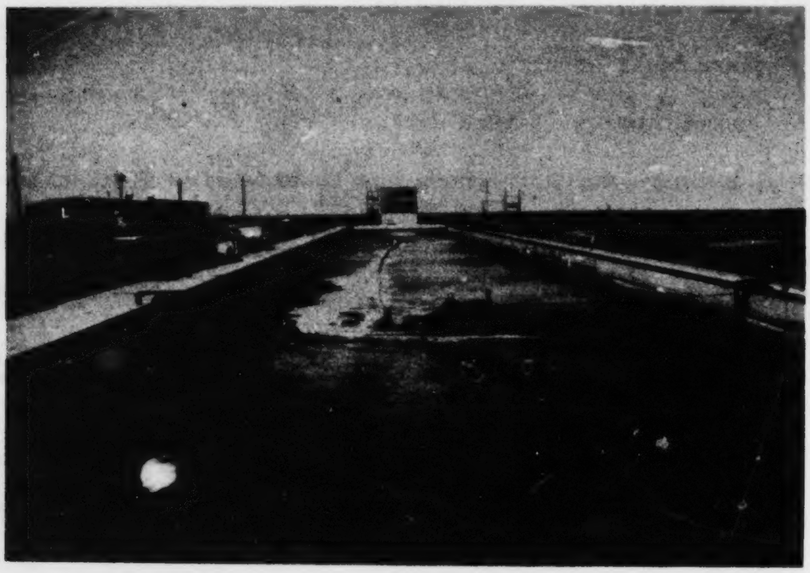

Figure 2. Photograph of diversionary configuration.

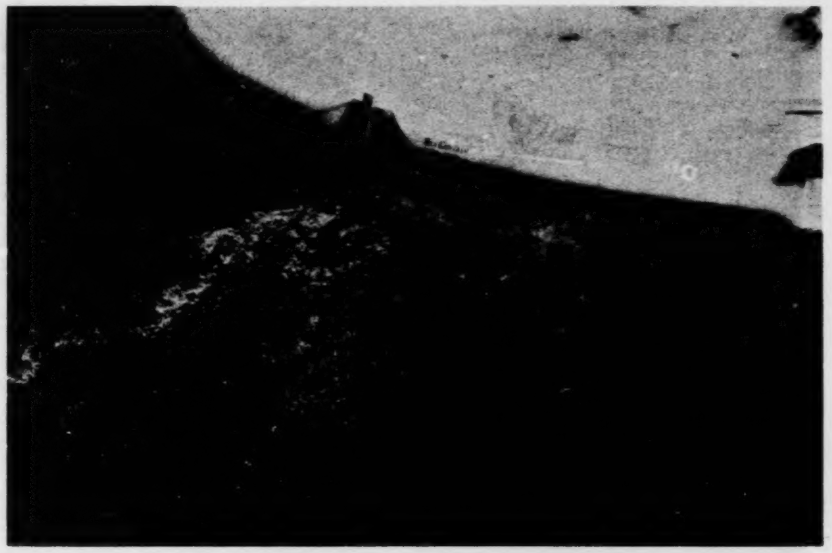

Figure 3. Photograph of oil entrainment (shedding) failure mode.

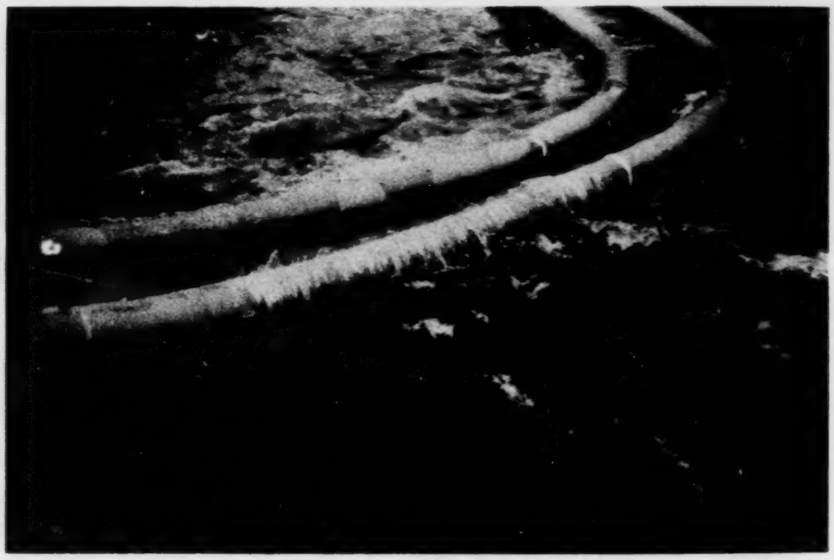

Figure 4. Photograph of oil splashover failure mode.

Figure 5. Photograph of planing failure mode.

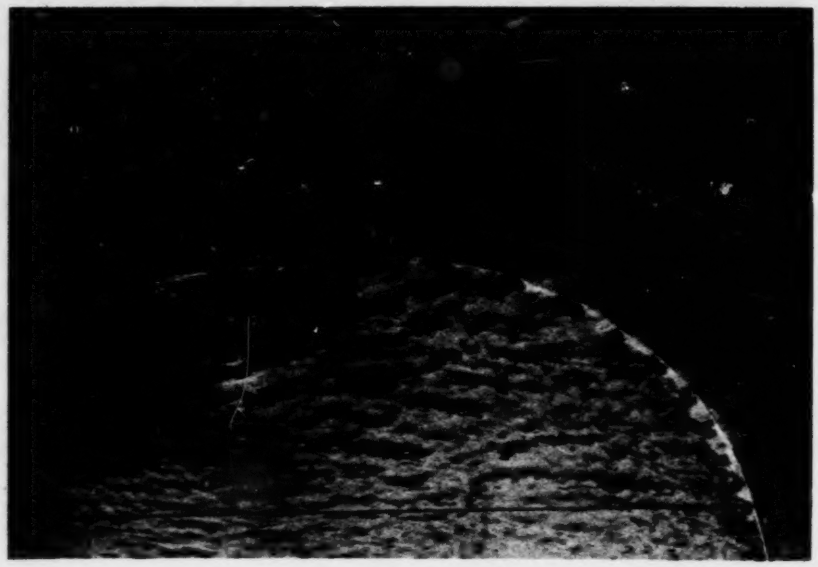

Figure 6. Photograph of submarining failure mode.

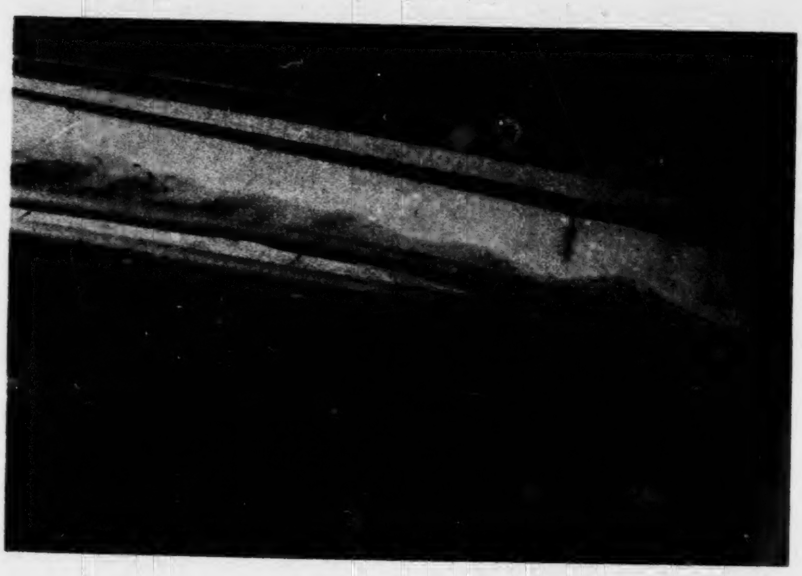

Figure 7. Photograph of bridging failure mode.

STANDARD TEST PLAN

A test plan was designed based on developing standard test procedures for evaluating oil control and recovery devices. Standard test parameters were defined to measure performance. The independent parameters of interest were: oil type, oil thickness, tow speed, waves and boom configuration. The dependent parameters for performance were defined as follows:

- Total Recovery Rate - (Skimmer) rate at which the equipment recovers oil/water mixture under test conditions.
- Oil Recovery Rate - (Skimmer) total recovery rate multiplied by the percent oil in the mix.
- Recovery Efficiency - (Skimmer) the percentage of oil recovered in the total mix.
- Stability Limit - tow speed at which boom loses its ability to maintain an adequate vertical profile.
- Critical Tow Speed - maximum speed the boom can be towed before losing oil under the skirt. Also called "no loss" tow speed.

The above mentioned independent parameters were tested over ranges defined according to the test rationale. The following ranges for these parameters were selected:

- Oil Type (properties varied with temperature and water content)
  - a. diesel fuel - viscosity of 0.1 cm^2/s (10 cSt), specific gravity of 0.852
  - b. lube oil - viscosity of 5.1 cm^2/s (510 cSt), specific gravity of 0.915
- Oil Slick Thickness
  - a. booms - 2 mm (.03 in)
  - b. skimmers - 2.54 cm (1 in)
- Tow Speed - 0 up to critical tow speed continuously controlled within 3.05 m/min (10 fpm)
- Wave Characteristics
  - a. height - 0.03 m, 0.6 m (1 ft, 2 ft)
  - b. period - 1.5. 3.0, 4.0, 6.0, infinite (sec)
  - c. steepness ratio - 0.013, 0.022, 0.066, 0.111

- Boom Configuration
  - a. catenary or containment (U-shape)
  - b. diversionary (J-shape)

Two types of skimmer tests were run. One test combined the skimmer with the diversionary boom to remove the diverted oil at the end of a test. This test represented field use of the total integrated boom/skimmer system. Other tests were conducted with a fixed area of 147.6 m^2 (1,588 ft^2) controlled in size by a pneumatic barrier. In terms of standardization and repeatability, tests conducted in the fixed area had the advantage over tests conducted in conjunction with diversionary barriers.

TEST MATRICES

To test the equipment with respect to the above mentioned variables, three separate matrices were developed:

1. Stability Test Matrix for Booms
2. Tow Test Matrix for Inland Booms
3. Test Matrix for Stationary Skimmers

The stability test matrix was designed to determine the critical (maximum) tow speed attainable for stable performance of containment and diversionary booms being towed through five sea water surface conditions (waves). The details of this matrix are given in Table 2.

The tow test matrix for inland booms was designed to determine the critical tow speed for no oil loss under catenary and diversionary booms being towed through the three most viable wave conditions identified from the stability tests. The details of this matrix are given in Table 3.

The test matrix for stationary skimmers was designed to measure the oil recovery rate and efficiency of a skimmer operating in the same three waves of the tow test matrix for booms and two oil types--diesel fuel and lube oil. The details of this matrix are given in Table 4.

Test No.	Boom Configuration	Tow Speed* (m/s)(kt)	Wave Character (m,m,s)(ft,ft,s) Height, Length, Period	Wave Generator Eccentric(in),CPM
1	Catenary	Vc ± (0.25) (0.5)	No wave	
2	Catenary	Vc ± (0.25) (0.5)	0.3 (1'), 13.7 (44'), 4.0	3, 15
3	Catenary	Vc ± (0.25) (0.5)	0.6 (2'), 9.1 (29'), 3.0	1.5, 40
4	Catenary	Vc ± (0.25) (0.5)	0.3 (1'), 22.9 (75'), 6.0	4.5, 10
5	Catenary	Vc ± (0.25) (0.5)	0.3 (1'), 2.7 (9'), 1.5	4.5, 20
6	Diversionary	Vc ± (0.25) (0.5)	No wave	
7	Diversionary	Vc ± (0.25) (0.5)	0.3 (1'), 13.7 (44'), 4.0	3, 15
8	Diversionary	Vc ± (0.25) (0.5)	0.6 (2'), 9.1 (29'), 3.0	1.5, 40
9	Diversionary	Vc ± (0.25) (0.5)	0.3 (1'), 22.9 (75'), 6.0	4.5, 10
10	Diversionary	Vc ± (0.25) (0.5)	0.3 (1'), 2.7 (9'), 1.5	4.5, 20

*Vc: Critical Tow Speed ± a total range of 0.25 m/s.

Table 2. Stability test matrix.

CATENARY

Test No.	Tow Speed (m/s) (kt)	Wave Character (m,m,s)(ft,ft,s) Height, Length, Period	Oil Type*	Volume Oil m^3(gal)
1	Vc ± (0.25) (0.5)	No wave	Lube	1.32 (348)
2	Vc ± (0.25) (0.5)	0.3 (1'), 13.7 (44'), 4.0	Lube	1.32 (348)
3	Vc ± (0.25) (0.5)	0.6 (2'), 9.1 (29'), 3.0	Lube	1.32 (348)
DIVERSIONARY				
4	Vc ± (0.25) (0.5)	No wave	Lube	1.32 (348)
5	Vc ± (0.25) (0.5)	0.3 (1'), 13.7 (44'), 4.0	Lube	1.32 (348)
6	Vc ± (0.25) (0.5)	0.6 (2'), 9.1 (29'), 3.0	Lube	1.32 (348)

* One boom system was tested with #2 Fuel Oil

Table 3. Tow test matrix for inland booms.

Pump rate set at optimum.

1.32 m^3 (350 gal) distributed for south end tests.

3.74 m^3 (1,000 gal) distributed for north end tests.

Slick thickness (based on measurements of collection area) 25 mm (1 in)

Test No.	Wave Character (m,m,s) (ft, ft) Height, Length, Period	Oil Type
1	No wave	Lube
2	0.3 (1'), 13.7 (44'), 4.0	Lube
3	0.6 (2'), 9.1 (29'), 3.0	Lube
*4	No wave	#2 Fuel
*5	0.3 (1'), 13.7 (44'), 4.0	#2 Fuel
*6	0.6 (2'), 9.1 (29'), 3.0	#2 Fuel

* Time Permitting

Table 4. Test matrix for stationary skimmers.

SECTION 6

TEST PROCEDURES

BOOM TOW TEST PROCEDURES

The first part of the boom test involved deployment and rigging of the boom. Depending upon the standard length per boom section, the length of boom used for the catenary configuration was approximately 60.96 m (200 ft) and for the diversionary configuration was approximately 30.50 m (100 ft). Boom sections were joined together and tow connections were rigged according to the manufacturers' recommendations. Light-weight chain, snap hooks and clevis connectors were used as much as possible to facilitate fast rigging and derigging. Also, a special monorail towing device, as shown in Figure 11, was constructed and used to support the trailing edge of the boom when testing in the diversionary mode. A light-weight boom was used as a "separation-boom" to simulate the shoreline quiet zone of a river and enable quantitative measurement of oil diverted.

For details of the catenary and diversionary test set-up, see Figure 8 and 9. To maintain a smooth diversionary profile against the relative current, a parachute mooring device was employed as shown. The exact lengths of booms tested are given in Appendix C.

After the boom was properly rigged and connected to the bridge, testing began. First, the stability tests were run according to the STABILITY MATRIX, Table 2. Once the water surface condition was established (wave or no wave), the boom was towed at continuously increasing speed until judged unstable by observation from the traveling truss located behind the boom apex. Then the tow speed was decreased in 3 m/min (0.1 kt) increments until the boom became stable and then increased by 3 m/min increments to reconfirm the failure speed. This speed was then entered as "critical tow speed" data. This established the upper limit on the range of tow speeds to be used in the following TOW TEST MATRIX FOR BOOMS with oil, Table 3. The failure point was also documented via 35 mm color slides and 16 mm color movie film. Modes of failure were noted and included as data.

The tow tests for booms in oil were conducted in a similar manner as the stability tests. Oil was distributed as a 2 mm thick spill, 15.24 m (50 ft) wide and amounting to about 1.32 m^3 (350 gal). Here the critical tow speed was defined as the maximum tow speed for either catenary or diversionary configurations at which there was no loss of oil under the boom. Other modes of oil loss were documented, but not used as the criteria

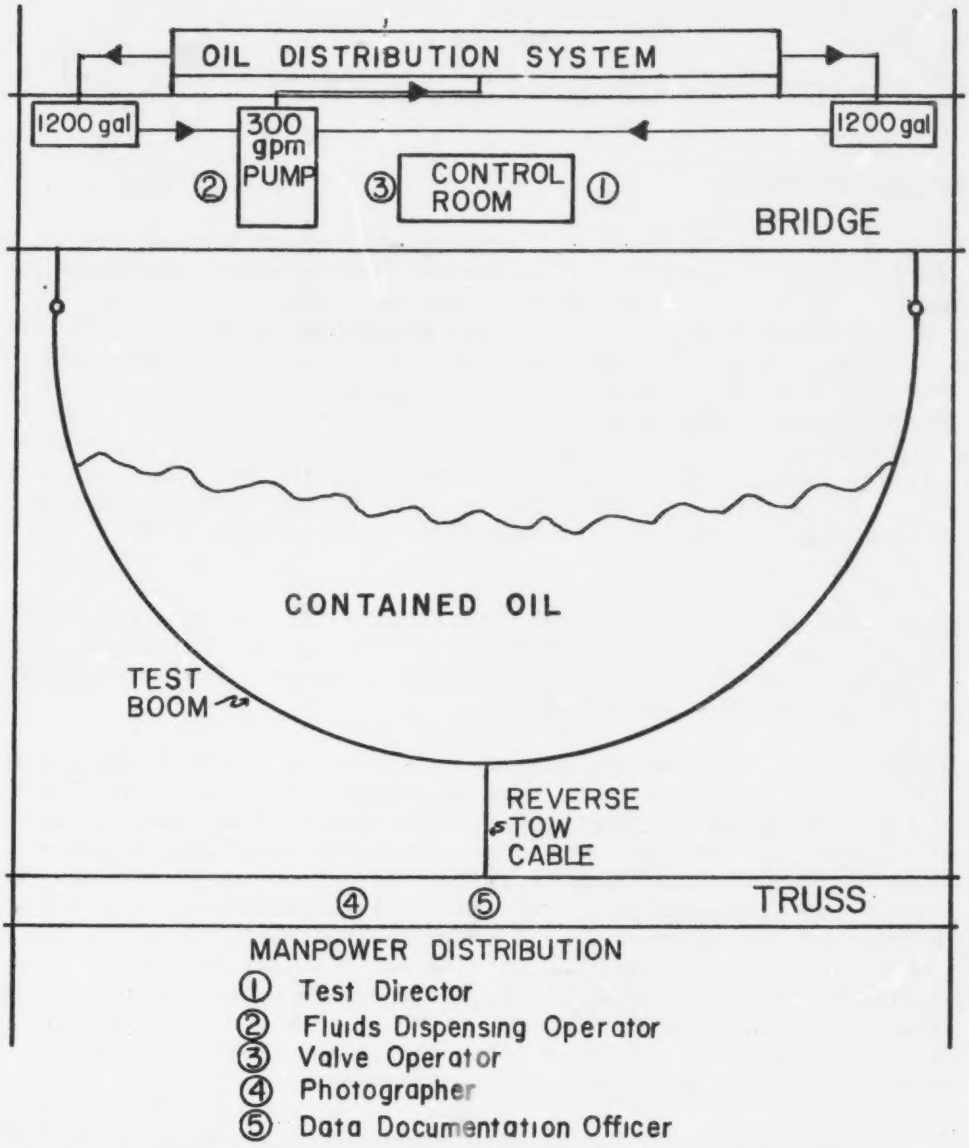
OIL DISTRIBUTION SYSTEM
1200 gal
300 gpm PUMP
1200 gal
②
③
CONTROL ROOM
①
BRIDGE
CONTAINED OIL
TEST BOOM
REVERSE TOW CABLE
④
⑤
TRUSS
MANPOWER DISTRIBUTION
① Test Director
② Fluids Dispensing Operator
③ Valve Operator
④ Photographer
⑤ Data Documentation Officer

Figure 8. Sketch of catenary boom test details.

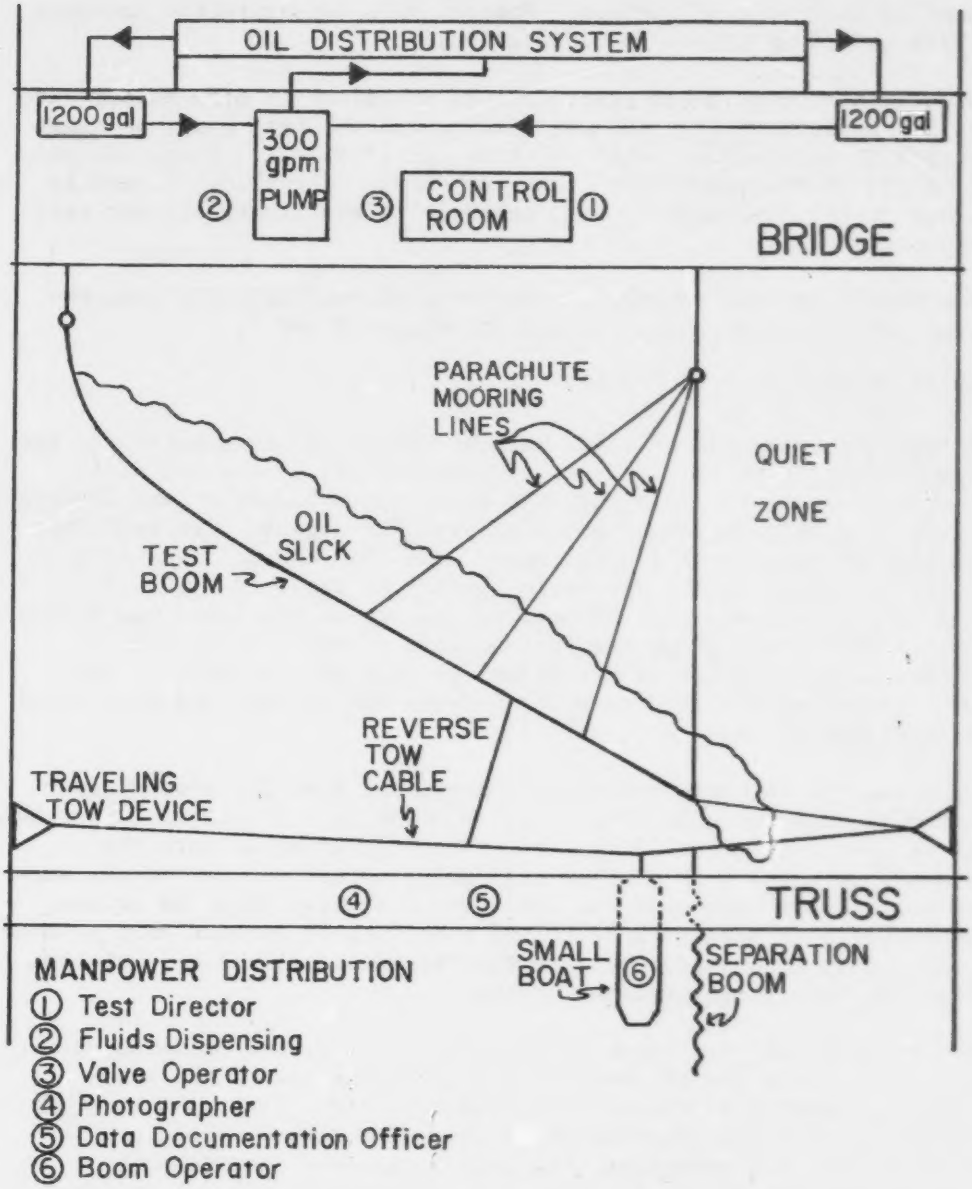
OIL DISTRIBUTION SYSTEM
1200gal
1200gal
300 gpm PUMP
CONTROL ROOM
②
③
①
BRIDGE
PARACHUTE MOORING LINES
QUIET ZONE
OIL SLICK
TEST BOOM
REVERSE TOW CABLE
TRAVELING TOW DEVICE
④
⑤
TRUSS
SMALL BOAT
⑥
SEPARATION BOOM
MANPOWER DISTRIBUTION
① Test Director
② Fluids Dispensing
③ Valve Operator
④ Photographer
⑤ Data Documentation Officer
⑥ Boom Operator

Figure 9. Sketch of diversionary boom test details.

for determining the maximum tow speed. The only exception was if a mode of failure, other than shedding, was prevalent at speeds significantly lower than the speed required for sheeding, then the maximum tow speed was based on that mode of failure. Photographic documentation included 16 mm film and 35 mm slides, both in color.

Diversionary boom tests with oil were considerably more complicated in that a "separation" boom was deployed behind the test boom, as shown in Figure 9 to separate diverted oil from all other oil. Thus, all oil contained within the separation boom was judged controlled. Generally, at the end of the diversionary boom test run, a stationary skimmer test was conducted.

Procedural details including manpower distribution and a step-by-step test run are given in Appendix G and Figure 8 and 9.

STATIONARY SKIMMER TEST PROCEDURES

Integrated boom/skimmer tests were conducted, while maintaining the same wave condition by collecting the separated oil at the end of a diversionary boom test. To accomplish this, the tow ends of the "separation boom" were brought together near the middle of the tank. Two rotatable barrels were mounted about 1 meter apart near the tank wall and well within the influence of the pneumatic barrier as shown in Figure 12. Each end of the boom was brought between and around the drums and pulled in opposite directions along the tank wall to corral the oil into a smaller pocket and thicken it for skimming. The air currents at the tank wall prevented oil from escaping between the barrels and maintained an oil thickness of about 2.54 cm.

Once the oil pocket was formed, the skimmer head was lowered over the tank wall into the oil. Since 1.33 m^3 (350 gal) of oil was distributed during the boom test and possibly all of the oil diverted into the separation boom area, 1.89 m^3 (350 gal) polyethylene recovery tanks were used to contain the recovered oil and water mixture. From the skimmer head there was a connecting hose to the pump (except for the ACME skimmer which had a pump mounted directly to the skimmer head) and a discharge hose from the pump to the recovery tanks.

The skimmer test run began by starting the pump and skimming operation. When recovered fluid was observed at the discharge end of the hose, a stopwatch was started to measure the recovery rate. The tanks were translucent so that periodic determinations of recovery rate could be made. As the oil was recovered, the boom pocket was diminished by drawing the boom around the barrels, thus maintaining the oil thickness. Eventually the boom pocket would enclose the skimmer with only a small volume of oil remaining as shown in Figure 10. The test terminated at this point and the length of testing time was noted.

By volumetrically measuring the recovered oil/water mix and the duration of the test run, total recovery rate was calculated and checked

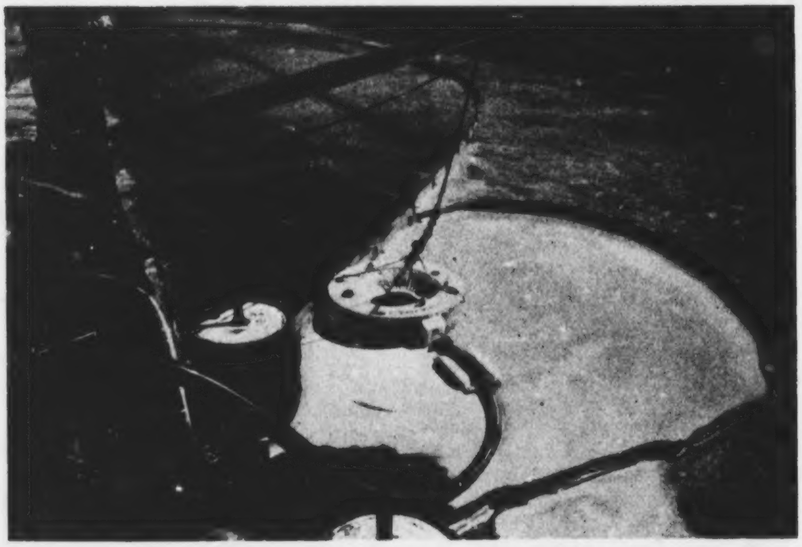

Figure 10. Photograph of skimmer test.

against the periodic determinations. After allowing the water to settle out of the oil by gravity for a minimum of one-half hour, the volume of water in the recovered mixture was read through the translucent tank walls. The percentage of oil recovered was calculted and documented as recovery efficiency. Oil recovery rate was then caluclated by multiplying the total recovery rate by the recovery efficiency.

Although the integrated boom/skimmer test simulated actual oil spill clean-up operations, it did not lend itself to standardization because of too many uncontrollable variables (e.g. boom pocket size, oil thickness, etc.) that affected test repeatability. Therefore, tests were also conducted at the north end of the test tank in a surface oil containment area defined by air barrier lines across the tank and along the tank walls encompassing 147.6 m^2 (1,588.8 ft^2) surface area as schematically shown in Figure 16. Tests were conducted in a similar fashion as described above and the test matrix is given in Table 4. Detailed test procedures are given in Appendix H.

Skimmer tests were documented photographically with 16 mm color motion picture film and 35 mm color slides.

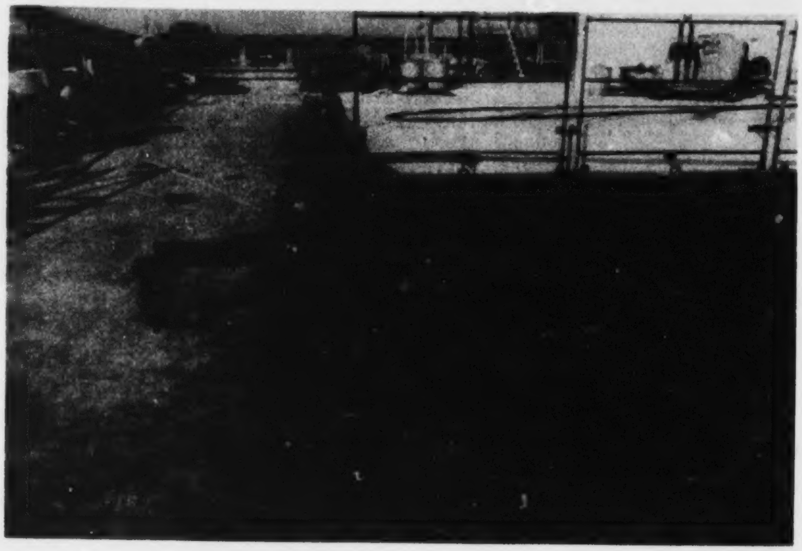

Figure 11. Photograph of traveling tow device.

SECTION 7

DISCUSSION OF RESULTS

BOOM TEST RESULTS

As mentioned in the Test Plan and Test Procedures sections of this report, the performance parameters measured for both diversionary and catenary testing of booms were: critical tow speeds for boom stability, critical tow speeds for oil contaiment and diversion, and modes of failure. All other performance information was either documented by comments or photographically. The raw data for the boom tests is given in Appendix E.

From the boom performance test data, the optimum boom stability performance in terms of maximum stable tow speeds for all booms tested was tabulated at each wave condition. These results are given in Table 5 for both catenary and diversionary boom configurations. Likewise, for performance in oil, optimum values of the maximum "no oil loss" tow speeds for all booms tested are given in Table 6.

The upper limit wave condition for all booms tested was the uniform breaking, short period wave--0.3 m (1 ft) high, 0.111 steepness ratio and 1.5 second period. Optimum stability performance of all booms in this wave was less than 0.25 m/s (0.5 kt) which is unacceptably low for most operations. Several test observations confirmed that oil could not be controlled in this wave condition at tow speeds approaching 0.25 m/s. This upper limit condition was carefully documented with 16 mm color movie film.

Optimum boom stability performance correlated quite well with wave steepness ratio (H/L). Performance steadily increased with decreasing H/L for catenary boom tests. Because of the use of a very stress-limited tow device, the actual optimum tow speed values could not be measured for booms towed in the diversionary configuration (Figure 11).

Optimum boom performance with oil was found to be governed by the oil shedding phenomenon at the oil/water interface. The tow speed at which oil is sheared away from the slick to form droplets has been theoretically shown to be 0.4 m/s (0.75 kt) in Reference 17 (this does not include the effects of waves and turbulence). Boom performance above this speed was then determined by its ability to prevent the droplets from escaping under the skirt. Once the speed necessary for interfacial shearing to occur was achieved, there appeared to be little

Table 5. Optimum boom stability performance (maximum stable tow speed).

WAVE CHARACTERISTICS		CONTAINMENT CRITICAL TOW SPEED m/s (kt)	DIVERSIONARY CRITICAL TOW SPEED m/s (kt)
H/L	H,L,P (m,m,s)(ft,ft,s)		
0.111	0.3 (1'), 2.7 (9') 1.5	FAILURE 0.25 (0.5)	FAILURE 0.25 (0.5)
0.067	0.6 (2'), 9.1 (29') 3.0	FAILURE 0.97 (1.94)	FAILURE 1.02+ (2.04)
0.022	0.3 (1'), 13.7 (45') 4.0	FAILURE 1.12 (2.24)	FAILURE 1.02$^+$ (2.04)
0.013	0.3 (1'), 22.9 (75') 6.0	FAILURE 1.14 (2.34)	FAILURE 1.02$^+$ (2.04)
0.0	CALM WATER	FAILURE 1.27 (2.54)	FAILURE 1.02$^+$ (2.04)

Table 6. Optimum boom performance with oil (maximum "no loss" tow speed).

WAVE CHARACTERISTICS		CONTAINMENT CRITICAL TOW SPEED m/s (kt)	DIVERSIONARY CRITICAL TOW SPEED m/s (kt)
H/L	H,L,P (m,m,s)(ft,ft,s)		
0.111	0.3 (1'), 2.7 (9') 1.5	OIL LOSS 0.25 (0.5)	OIL LOSS 0.25 (0.5)
0.067	0.6 (2'), 9.1 (29') 3.0	OIL LOSS 0.46 (0.92)	OIL LOSS 0.81 (1.62)
0.022	0.3 (1'), 13.7 (45') 4.0	OIL LOSS 0.46 (0.92)	OIL LOSS 0.71 (1.42)
0.0	CALM WATER	OIL LOSS 0.46 (0.92)	OIL LOSS 0.81 (1.62)

the boom could do to prevent oil loss. This could explain the lack of correlation between performance with oil and the wave steepness ratio (See Table 6). Except for the breaking wave (H/L = 0.111), there was no correlation of optimum boom performance in oil with the waves tested.

The purpose of stability testing the booms in the 0.3 m (1 ft) x 22.9 m (75 ft) x 6 s wave was to determine if excessively high tow tension resulted when the boom system dimension coincident with the direction of wave propagation nearly equalled the wave length. Resonance did occur at the test condition when these two dimensions were nearly equal. Tension forces exceeded 454 kg (1,000 lb) during one catenary boom test, sheared a steel bracket supporting the tension load cell and destroyed the transducer. It was enough to confirm the harmonic excitation problem and it ended all measurement of tow tension.

Diversionary boom deployment allows a boom system to perform effectively in higher currents than when deployed in a catenary configuration. The angle which the boom makes with the fast current determines its performance. Knowing this angle and the velocity of the current, a simple trigonometric calculation gives the component of the current perpedicular to the boom. In theory, if the boom angle can be adjusted to maintain the perpendicular component of the current below that value at which the catenary boom fails, then the boom will successfully control the oil spill. This benefit was experimentally tested. Test results of the booms in both configurations are presented in Table 7. As expected, the full benefit of angling the boom with the current was not obtained. The main reason was the inability to maintain a constant angle along the entire length of the boom. Unlike a moving body of water, the velocity profile across a towing tank is constant. This proved to be critical and caused failure at lower velocities than predicted.

One clear benefit of angling a boom to the current was the downstream water flow pattern next to the boom. Entrained oil droplets escaping under the boom would tend to collect in the water flowing along the backside of the boom and ultimately be collected within the "separation" boom shown in Figure 9. However, as the tow speed was incrementally increased above the "no oil loss" speed the droplets were driven deeper into the water column and completely escaped this secondary controlling effect of the boom.

With the exception of one trial, all boom tests were conducted with Sunvis 75, a lubrication oil without additives. To measure the effect of low viscosity oil on boom performance, one boom was tested with both the lubrication oil and diesel oil. The results indicated a slight decrease in the critical tow speed of 0.07 m/s (0.14 kt) when tested in diesel oil.

STATIONARY SKIMMER RESULTS

The performance parameters measured for stationary skimmer systems were oil recovery rate and efficiency. Two types of oil were tested:

Table 7. Computed diversionary "no loss" tow speeds from catenary "no loss" speeds using angular component technique.

VERALL NGLE ° ETWEEN B OMS AND URRENT	WAVE CONDITION Height, Length, Period		CATENARY		DIVERSIONARY			
			(observed)		(calculated)		(observed)	
	m, m, s	ft, ft, s	m/s	fpm	m/s	fpm	m/s	fpm
23	No Wave		.33	65	.84	166	.46	90
23	.3,13.7,4	1, 45, 4	.33	65	.84	166	.46	90
23	.6, 9.1,3	2, 30, 3	.33	65	.84	166	.46	90
24	No Wave		.43	85	1.05	207	.61	120
24	.3,13.7,4	1, 45, 4	.43	85	1.05	207	.71	140
24	.6, 9.1,3	2, 30, 3	.46	90	1.11	219	.51	100
24	No Wave		.43	85	1.05	207	.41	80
24	.3,13.7,4	1, 45, 4	.38	75	.93	183	.41	80
4	.6, 9.1,3	2, 30, 3	.43	85	1.05	207	.41	80
4	No Wave		.46	90	1.11	219	.71	140
4	.3,13.7,4	1, 45, 4	.46	90	1.11	219	---	---
4	.6, 9.1,3	2, 30, 3	.46	90	1.11	219	.71	140
2	No Wave		.25	50	.56	111	.81	160
2	.3,13.7,4	1, 45, 4	.30	60	.68	133	.51	100
2	.6, 9.1,3	2, 30, 3	.43	85	.90	177	.81	160

Table 7 (continued).

OVERALL ANGLE [illegible] BETWEEN BOOMS AND CURRENT	WAVE CONDITION Height, Length, Period		CATENARY		DIVERSIONARY			
			(observed)		(calculated)		(observed)	
	m, m, s	ft, ft, s	m/s	fpm	m/s	fpm	m/s	fpm
30	No Wave		.51	100	1.02	200	.61	120
30	.3,13.7,4	1, 45, 4	.46	90	.91	180	.61	120
30	.6, 9.1,3	2, 30, 3	.25	50	.51	100	.41	80
34	No Wave		.46	90	.70	137	.43	85
34	.3,13.7,4	1, 45, 4	.36	70	.54	106	.46	90
34	.6, 9.1,3	2, 30, 3	.36	70	.54	106	.38	75
44	No Wave		.20	40	.29	57	.30	60
44	.3,13.7,4	1, 45, 4	---	---	----	---	.25	50
44	.6, 9.1,3	2, 30, 3	.18	35	.25	50	.23	45

diesel oil and lubrication oil. These represented the extremes in oil viscosity with a range from 32.6 cm^2/s (3,260 cSt) to 0.1 cm^2/s (10 cSt). In general, the oil slick thickness was controlled at 2.5 cm (1 in) to represent actual inland-use situations where oil is thickened prior to removal via skimming devices. The raw data for the skimmer tests is given in Appendix F.

From the performance test data, the optimum skimmer performances were denoted and the effect of viscosity on performance was qualitatively obtained. Test results are given below in Table 8.

TABLE 8. OPTIMUM SKIMMER TEST RESULTS

Optimum Performance	Oil Type	Skimmer Type
Maximum Oil Recovery Rate		
2.54×10^{-3} m^3/s (40 gpm)	Lube	Adjustable Weir
1.39×10^{-3} m^3/s (22 gpm)	No. 2 Fuel	Floating Suction Head
Maximum Efficiency % Oil in Oil/Water Mix		
99%	Lube	Rotating Disc
99%	No. 2 Fuel	Rotating Disc

Since the purpose of these tests did not include direct comparisons between manufacturers' skimmers, skimmer types were defined and used to express the performance results. Also, it was recognized that the performance of a skimming system depends upon every component of that system; skimmer head type, connection hose dimensions, pump type and capacity, and the discharge hose dimensions. The types of skimmer heads tested are defined as:

- The rotating disc type--oleophilic discs rotate through the oil and water. Oil collects on the discs via viscous friction and is wiped off into a collection sump for pump-out.

- The self-adjusting weir type--a floating weir box collects oil until the sump is filled to capacity. As oil intake exceeds oil pump-out, the weir tilts, stopping oil intake. As oil pump-out lowers the level in the sump, the weir tilts back into oil skimming operation.

- The adjustable weir type--floating weir box that is manually adjusted for thickness of skimmed layer.

- The floating suction head type--buoyant suction head and connecting hose, float partially submerged in the oil to skim off thick layers of oil.

Most inland spills are not of a catastrophic nature such as oil tanker spills at sea. Therefore, the typical inland skimmer systems are sized for recovering the smaller spills at pumping rates of 3.15 to 6.31 x 10^{-3} m^3/s (50 to 100 gpm). If the skimmers tested are considered representative of the current technology (not to include vacuum trailers which are used for large and small spills, if accessible), the maximum oil recovery rate (not including recovered water) was 2.54 x 10^{-3} m^3/s (40 gpm) and the highest percent of oil recovered oil/water mix was 99%. For the viscous oils, hose diameters and lengths 7.6 cm (3 in) and 15.2 m (50 ft) worked best for the pumps involved. Also, diaphragm pumps perform much better in viscous oils than axial flow or centrifugal pumps.

Of the waves tested, there was no clean correlation of skimmer performance and wave conditions. In some cases there seemed to be a slight improvement and in other cases a slight decrease in performance with certain waves. In general, these differences were small enough to be explained by the inaccuracies of test measurement.

EXPERIMENTAL ERRORS

Basically two types of accuracy are important to the results of this test project. One is the accuracy with which the independent and dependent variables were measured (e.g. tow speed). The other is the accuracy of tank testing, or phrased differently, the correlation between tank testing, field testing and field use. The first one is considered here and the second one is discussed in the following section of Application of Testing and Test Data.

The test matrix specifies the desired nominal conditions for a given test. For any test run, the measured independent variable did not deviate from the nominal values by more than the following percentages:

Tow speed	10%
Wave height	10%
Wave length	10%
Wave period	5%
Oil application rate	5%

These deviations were based on the following comparative analysis: Tow speed data was collected using a pulse generating wheel apparatus in direct contact with the towing cable and compared to the digital voltmeter. Wave characteristics: expected vs. observed parameters were compared using visual observation of wave profile against a sealed grid painted on the east tank wall, and photographic documentation. Oil application: a flow rate comparison was performed by timing the fluid output into measured recovery tanks. The accuracy of recovery measurements is based on the thickness of the oil phase within the recovery barrel, and the ability to read fluid levels to the nearest 0.16 cm (1/16 in). In the majority of test cases, the thickness of the oil phase was greater than 5.08 cm and increments of 0.16 cm (1/16 in) were readable. The maximum error of these readings is expected to have been not more than 10%.

SECTION 8

APPLICATION OF TESTING AND TEST DATA

DEFINE OPERABILITY RANGES

One very important application of performance test data from OHMSETT is the relationship between the measured performance of the test equipment and to simulated environmental conditions. Aside from wind effects, which are usually considered of secondary importance relative to waves and currents, most waterway environments can be simulated quite adequately. With the capability of varying wave height (0 → 0.91 m), period (1 → ∞) and steepness ratio (0.5 → 0.005) in a continuous fashion with wave flap rpm control (±1 rpm), and tow speed (simulated current) from 0 → 3.05 m/s (±0.05 m/s), the performance is closely correlated with environmental conditions and upper limits are closely defined where performance drops off and becomes unacceptable. If this were accomplished for all types of spill control and clean-up equipment, both the potential user and the equipment manufacturer would benefit greatly. The user would benefit from knowing precisely what type of equipment is needed for the environmental conditions in which equipment is intended to be used. He would not have to personally experiment with elaborate and expensive equipment to find whether or not it meets his needs. The manufacturer would benefit by knowing how to better design equipment to perform in various environments. Also the specifications and guarantees on equipment, if closely correlated, would result in satisfied customers and improved business.

There are many benefits to all concerned with oil spill control and clean-up whether they be government agent, consultant, manufacturer or user. The tests described in this report could possibly find application to this end.

OPERATING TECHNIQUES

Several techniques found useful in operating the test equipment can be passed on to potential users. Even though some of the techniques are found in the manufacturers' operating instruction manuals, they are worth repeating along with the introduction to some new ones. Techniques used included: connecting tow lines to the boom tension members, mooring point selection, fabrication of a "parachute mooring" arrangement for diversionary configuration and revolving drum system for maneuvering a large amount of boom to form a small pocket of thickened oil.

If towing connections must be made to a boom without a bridle or connection plate, a chain of proper gauge (but not too heavy) and strength acts as a very good bridge when connected between the ballast line and the upper tension line. By fastening snap-hooks to the ends of the towline, they can easily be connected at various links along the chain. This was done for one boom system that had one tension line at the floats and another at the ballast. After some trial and error, the optimum point of towline connection to the chain was found to be one-third up from the bottom. And it was also shown as an overall test result, that when the tow force (or force profile) is concentrated near the bottom, towing performance was optimized. Also, in conjunction with this, the towline should be moored at the same elevation as the boom-connection point to avoid either tending to lift the boom skirt out of the water or submerging the boom floats. This arrangement gave the most satisfactory results.

A universal "parachute mooring" arrangement can be easily made from aluminum plate, chain and towlines as mentioned above. The plates should be cut long enough to span the entire height of the boom plus room for bolting back and front plates together above and below the boom. The plates are normally 15.24 cm (6 in) wide and usually fit between flotation members along the boom. The chain should be connected to the plate with eye bolts and clevis. Towlines with snap-hooks are connected to a common ring which is moored at the other end. Depending upon the situation, several connection plates would be spaced along the boom with towlines connected and moored to a common mooring line. This could be at several segments of boom with several separate "parachute mooring" rigs. The linkages were adjusted until the boom conformed to the desired configuration with respect to the current. The "parachute mooring" arrangement used for this project is shown schematically in Figure 9.

Part of the diversionary boom test consisted of taking a large amount of boom containing the diverted oil thinly spread out over its entire length and pulling the two ends together and around two revolving drums to form a small thickened pool or oil for optimum skimming operation. Two 0.20 m^3 (55 gal) drums were found to have the necessary diameter for smoothly pulling the light boom around the drums in a controlled manner even while 0.6 m (2 ft) waves were acting upon it. The drums were cut out at the bottom and vented at the top before being mounted on 5.1 cm (2 in) steel pipes through 6.4 cm (2.5 in) steel pipe pieces radially braced and welded so that the drums could freely rotate about the support pipe while half submerged in water and yet be rigid enough to withstand the forces involved in this operation. This set-up worked very well for the test project and could have field application especially where industrial operations near the shorelines require a permanent or semi-permanent state of preparedness for potential spills (Figure 12).

For skimmers, the principle techniques included the type of pump to use and the effect of hose dimension of oil recovery rate. When recovery pumps are required to pump $3.2 \rightarrow 6.3 \times 10^{-3}$ m^3/s (50 → 100 gpm) of oil with viscosity greater than 432×10^{-6} m^2/s (2,000 SSU), a diaphragm pump was found to work best with 7.6 to 10.1 cm (3 to 4 in) connection

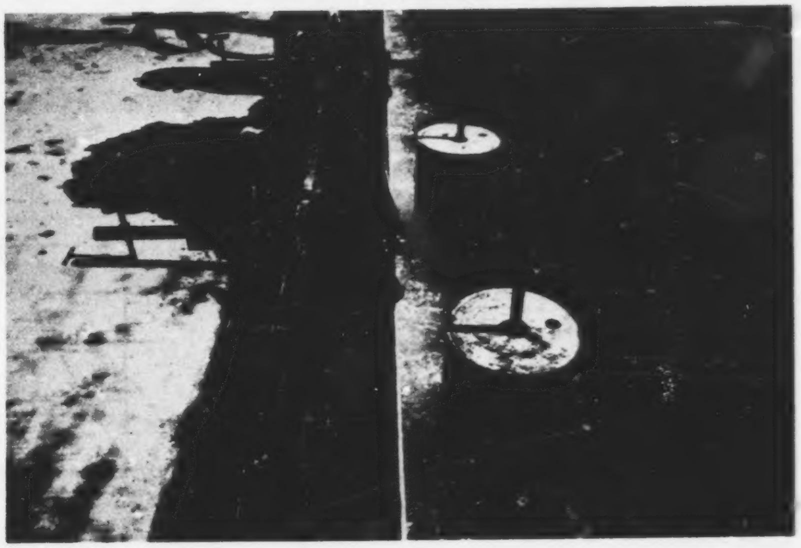

Figure 12. Photograph of rotating drums.

and discharge hoses.

TEST TANK EFFECTS ON DATA

Test tanks can only approximate actual waterways. There is no real current (except with flumes) and the waves are affected by the finite depth. No doubt a separate report would be needed to rigorously define all of the differences. However, the primary differences are that the waves are mechanically generated, shallow-water waves, and the currents are simulated by relative motion of the traveling bridge with respect to "motionless water". Also there are air generated currents from an air barrier system which lies along the bottom of the tank, near the walls. Perhaps the best way to describe the difference in water current profile is to illustrate it schematically for a test tank and representative river profile. See Figures 13 and 14.

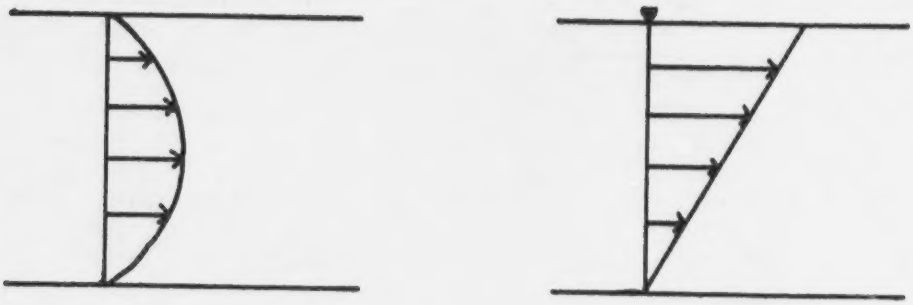

Figure 13. Sketch of river velocity profiles.

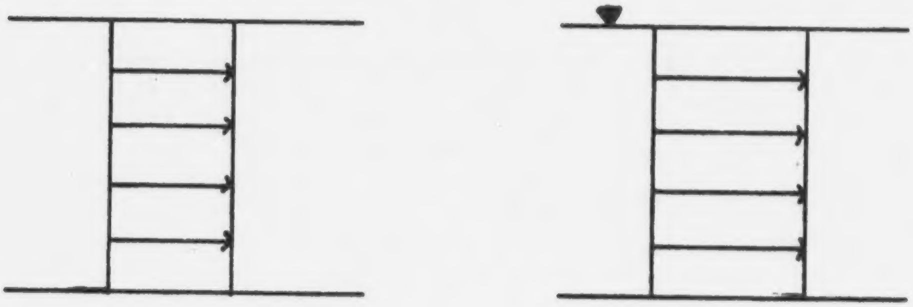

Figure 14. Sketch of test tank relative velocity profiles.

From the schematic diagrams, there appears to be no great difference between the two bodies of water. Some could even say that for rivers with very steep banks, the surface velocity profile becomes nearly flat, which is true for some cases. However, for most cases, when the diversionary technique is being applied, the very reason for setting the boom at a smaller angle with the mid-stream current is to avoid those currents greater than 0.51 m/s (1 kt) from directly encountering the boom and causing oil loss entrainment). Ideally, the fast mid-stream currents are used to divert oil to the much slower current zone near the shoreline. When testing this concept in the test tank, obviously, there is no "slow current" zone. The bridge moves with respect to the tank water and this relative velocity is the same all across the tank.

How does this affect the correlation of diversionary boom performance between the test tank and the real world? Boom failure occurred at the trailing end which was angled the most against the current and should have been in the "quiet zone" which does not exist in a test tank. If a "quiet zone" did exist near the test tank wall (or trailing edge of the boom), the "no oil loss" test speed would have increased and been in closer agreement with the calculated values (see Table 7) and actual performance in waterways with parabolic surface profiles and "quiet zones". The result is that the diversionary "no oil loss" tow speeds are low and conservative.

As for waves, mechanically driven in the test tank, they are categorized as shallow-water waves since the water depth 2.4 m (8 ft) never exceeds the wave length capabilities of the wave generator. The significance of this is twofold: 1) for wind driven waves on deep inland waterways, the reproducibility of the wave generator will not be as close as with shallow-water waves, and 2) the turbulent effects of waves will extend to the tank bottom and thus their shape will be influenced by the bottom and its contour. A wave study to define the significant wave characteristics and wave spectra is planned for the near future. Until this is done, it is difficult to intelligently argue the differences between test tank waves and wind driven waves that are statistically defined and categorized via wave spectra.

Apparently the turbulent effects of the waves tested were not significantly affected by the shallow, flat bottom. At least the effect on the critical current at which oil entrainment begins was insignificant in that good agreement with the well established value of 0.38 m/s (0.75 kt) was confirmed. However, the effect of a shallow, flat bottom on turbulence, orbital current and internal waves should be investigated and well defined.

There is an additional effect in the OHMSETT test tank that is perhaps unique--an air bubbler barrier system. The air barrier system is designed to protect the walls, beach and wave flaps as shown photographically in Figure 15 and schematically in Figure 16.

Surface currents from the air bubbles have been observed 6.1 m (20

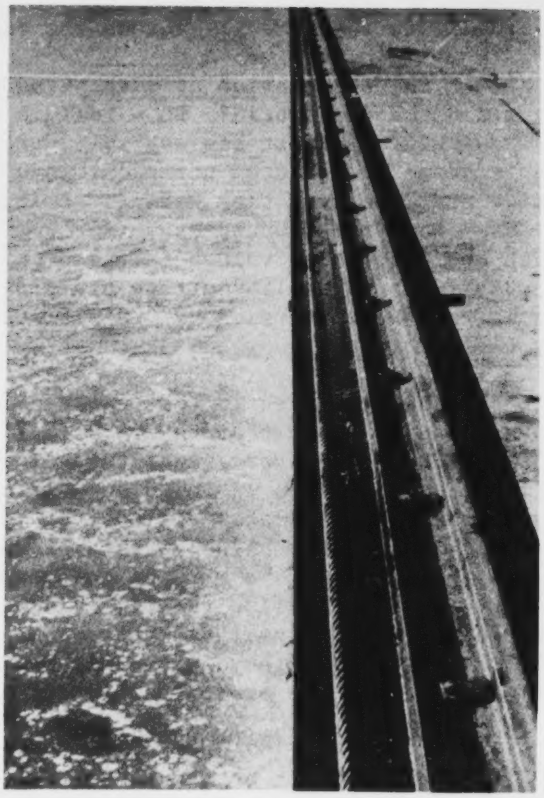

Figure 15. Photograph of air barrier surface currents.

ft) from the wall where they originated and at speeds up to 0.3 m/s (0.6 kt) near the wall. Although accurate measurements have not been made, hydrodynamic principles dictate orbital currents and vertical velocity profiles are generated by the rising air bubbles. The circulation pattern and velocity profiles are schematically shown in Figure 17. Here again this effect should be defined with measurements and photographs to rigorously defend the test results and their relevance to the real world. Tests have been conducted with and without the air barrier with no measurable difference in results when testing with booms. This plus the above mentioned agreement with the critical velocity of catenary booms on calm waters tend to argue against the need of costly measurements of orbital circulation patterns and velocity profiles.

In conclusion, the test tank effects on the test data have not been quantitatively documented at OHMSETT. Qualitatively, such effects can be argued to have had negligible influence on the test data of this particular test project. However, until these effects are quantified, all test tank data will not be rigorously proven to have a direct 1:1 relationship to the waterways and the real world.

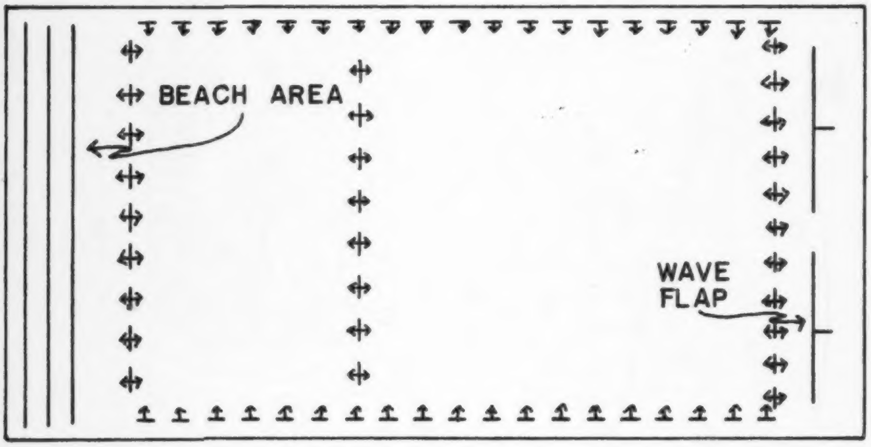

Figure 16. Sketch of air barrier surface currents.

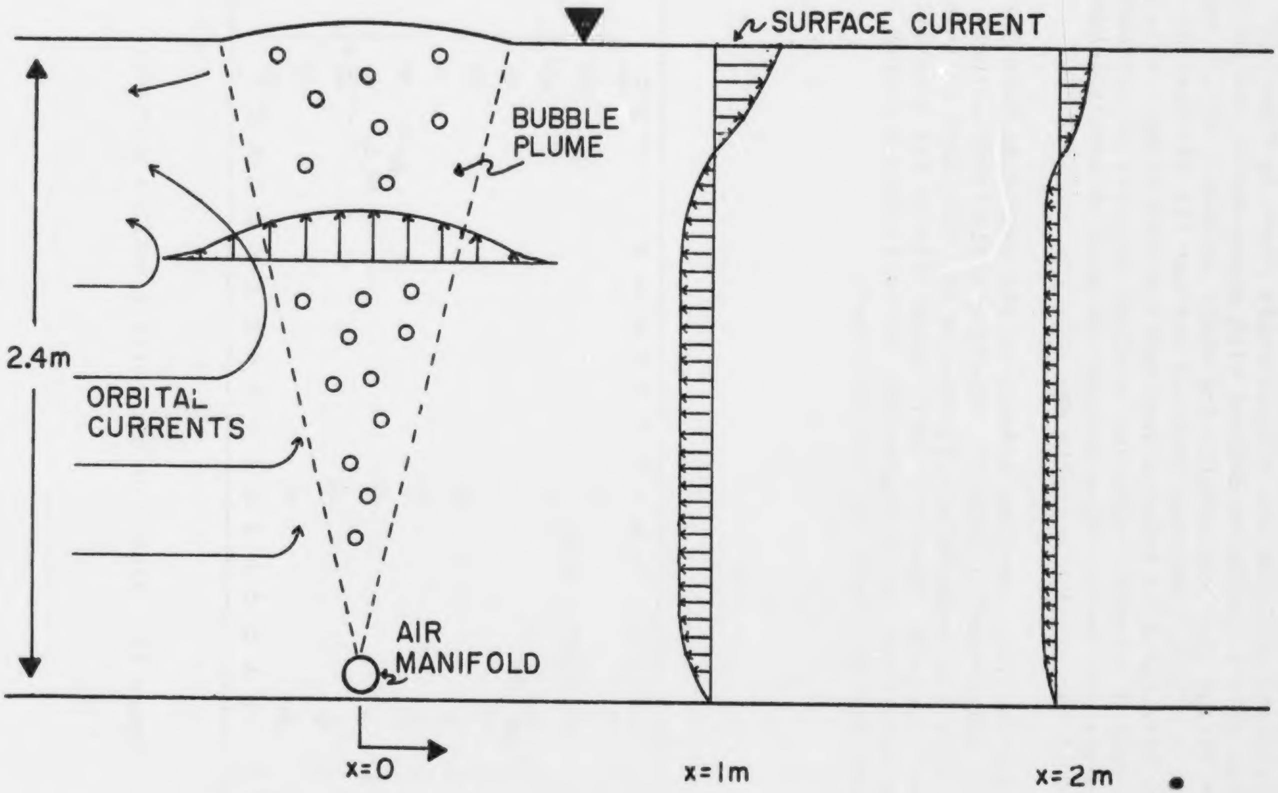
SURFACE CURRENT
BUBBLE PLUME
2.4m
ORBITAL CURRENTS
AIR MANIFOLD
x=0
x=1m
x=2m

Figure 17. Circulation pattern and velocity profiles for an air barrier.

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APPENDIX A

OHMSETT DESCRIPTION

United States Environmental Protection Agency

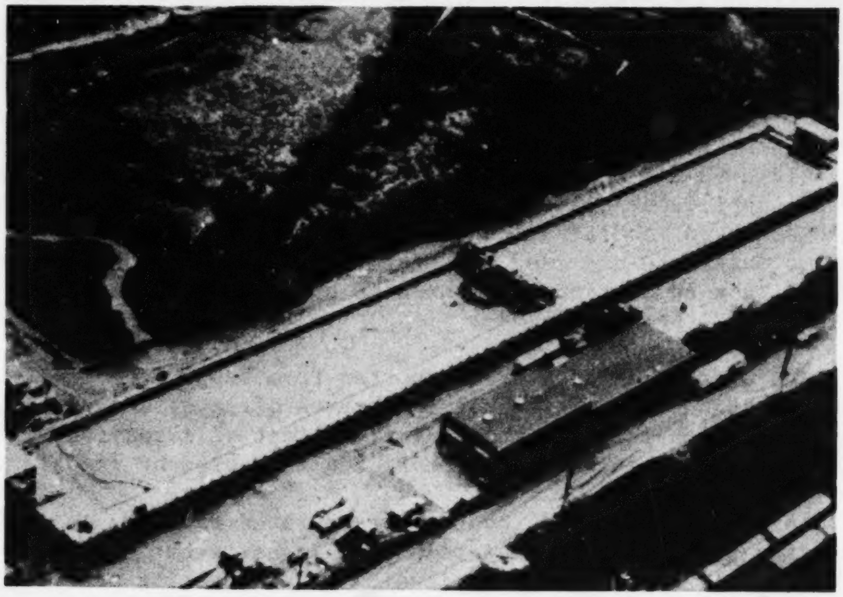


Figure A-1. Photograph of OHMSETT.

The U.S. Environmental Protection Agency is operating an Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous materials spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203.3 m (667 ft) long by 19.8 m (65 ft) wide and with a depth of 2.44 m (8 ft). The tank can be filled with fresh or salt water. The tank is spanned by a towing bridge with a capability of towing loads up to 15422.4 kg (34,000 lb) at speeds to 3.05 m/s (6 kt) for a duration of 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil on the surface of the water several feet ahead of the device being tested, such that reproducible thicknesses and widths of oil slicks can be achieved with minimum interference by wind.

The principle systems of the tank include a wave generator and beach, a bubbler system and a filter system. The wave generator and absorber beach have capabilities of producing minimum reflection waves to 0.61 m (2 ft) high and 24.38 m (80 ft) long, as well as a series of reflecting, complex waves meant to simulate the water surface of a harbor or estuary. The water is clarified by recirculation through a 1.26 m^3/s (2,000 gal/min) diatomaceous earth filter system to permit underwater photography and video imagery, and to remove the hydrocarbons that enter the tank water a a result of testing. Oil is controlled on the surface of the water by a bubbler system which prevents oil from reaching the tank walls, the beach or the wave generator. This system is designed to speed clean-up between test runs. A clean tank surface is essential to reproducible oil spill conditions. The towing bridge has a built-in skimming board which, in conjunction with the bubbler system, can move oil to the North end of the tank for clean-up and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume 9842 m^3 (2,600,000 gal) is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized equipment will be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon adsorption unit which is availabe for removal of organic materials from the water.

Tests at the facility are supported from a 650 square meter building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test oils and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis to government agencies at the Federal, State and local levels. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a staff of eleven multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology, and overall project direction.

For additional information, contact:

OHMSETT Project Officer
U.S. Environmental Protection Agency
Research & Development
Edison, New Jersey 08817
Phone: 201-321-6600

APPENDIX B

FACILITY MODIFICATIONS

TRAVELING TRUSS

In that the boom tests required an observer near the boom apex to make determinations of oil loss mechanisms and boom stability, construction of a traveling truss was necessary. The truss was designed to span the tank from rail to rail and with wheels to fit the rails so that it could be towed along with the bridge. The walk-way on the truss was designed to accommodate one row of observers across the width of the tank. The truss is shown in Figure B-1. Only limited loads are attached to the truss--907 kg (2000 lb) maximum at the center.

Other useful purposes have been found for the truss. Photographs from virtually any vantage point can be accomplished since the truss can be stationed at any position behind or in front of the bridge. Also, a light-weight skimming boom was mounted on the truss and dropped into the water at the end of a test run to move residual oil into the surface containment area at the north end of the tank. Thirdly, the truss acts as a tow-back system for returning test equipment to the starting position.

OIL DISTRIBUTION SYSTEM

Existing oil distribution equipment mounted on the bridge was designed for 0.189 m^3/min (50 gpm) and thin film studies. Other projects, including this one, required higher distribution rates up to 1.134 m^3/min (300 gpm) for various slick thicknesses and tow speeds. The oil distribution system was composed of a pump, positive displacement flow meter and flow-rate meter, two sets of spray nozzles (high viscosity and low viscosity) and associated piping and instrumentation. A photograph of the spray nozzle system is shown in Figure B-2. There was a total of 14 nozzle connectors equally spaced over a 18.2 m (60 ft) span. Each connector pipe was joined to a nozzle set with hand valves for flow control. The high viscosity nozzles were used for this test project.

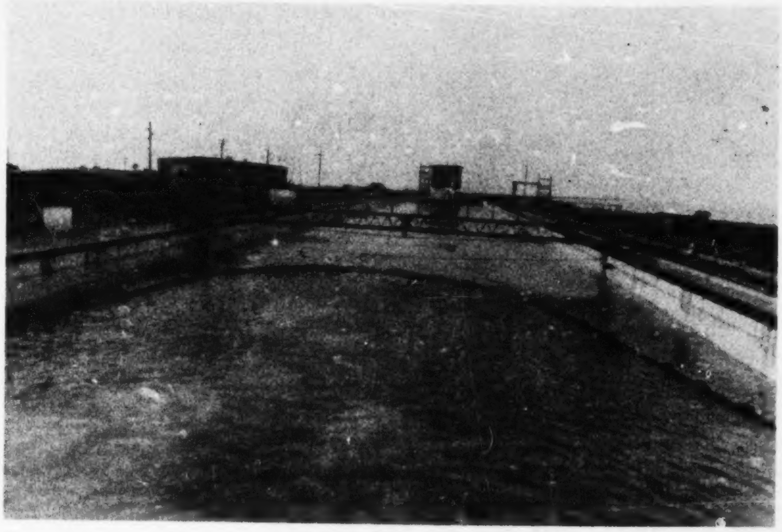


Figure B-1. Photograph of truss.

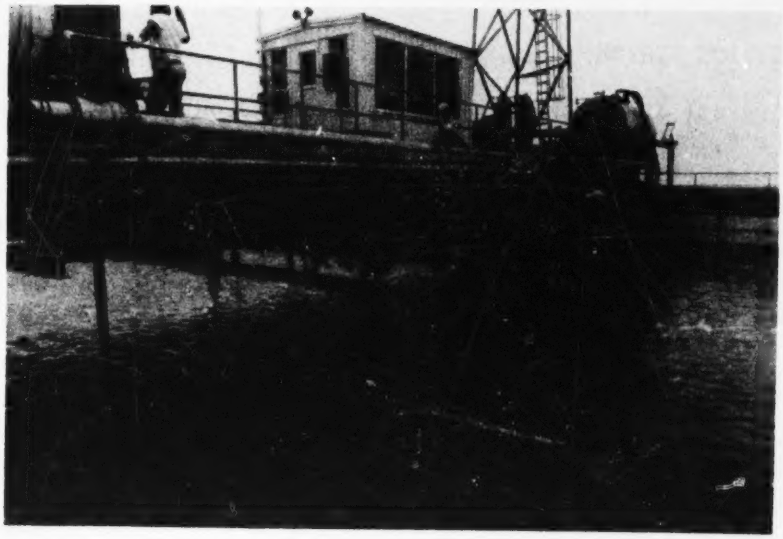


Figure B-2. Photograph of oil distribution system.

APPENDIX C

TEST EQUIPMENT

BOOMS

The following section of this manual describes the individual boom systems tested. Individual systems are detailed in the following manner:

Manufacturer--Name of system
Design characteristics
Tow point connections
Comments

Diagrams and photographs of devices, sketches of tow point connection, and rigging specifications are given separately following the above details in this appendix.

Certain materials are reprinted courtesy of the individual manufacturers.

CLEAN WATER, INC. - HARBOUR BOOM

Design Characteristics

(1) Draft - 0.61 m (24 in)
(2) Freeboard - 0.20 m (8 in)
(3) Flotation - expanded polyethylene cylinders 0.15 m (6 in) x 0.46 m (18 in) length
(4) Ballast - 0.635 cm (0.25 in) galvanized chain, pocketed along bottom of skirt
(5) Skirt material - nylon reinforced, oil resistant PVC heavy-duty sheet encasing
(6) Tension member - 0.794 cm (0.312 in) coated aircraft cable threaded through float cylinders. Second tension member is ballast chain.
(7) Weight - 3.04 kg/m (2.04 lb/ft)
(8) Excess buoyancy - 4.02 kg/m (2.70 lb/ft)
(9) Available in 15.2 m (50 ft) sections.

Tow Point Connection

(1) A bridle arrangement was connected top and bottom to coated air craft cable and ballast chain. This then was connected to bridge tow points.

Comments

(1) Articulation between flotation elements facilitates handling and storage, but caused interfloat regions to slacken during test runs resulting in loss of freeboard. The addition of slack retaining lines on the boom at these points would reduce this effect.
(2) The boom required three men per section for handling and was relatively easy to deploy and make connections.

COASTAL SERVICES - T-T BOOM

Design Characteristics

(1) Draft - 0.30 m (12 in)
(2) Freeboard - 0.15 m (6 in)
(3) Flotation - polyethylene cylinders 0.10 m (4 in) diameter x 0.23 m (9 in) length
(4) Ballast - 0.635 cm (0.25 in) galvanized chain along bottom of skirt
(5) Skirt material - oil resistant PVC nylon reinforced fabric
(6) Tension member - self-tensioning boom using end plates, fast eye snap hooks; magnetic attachments available
(7) Weight - 2.46 kg/m (1.65 lb/ft)
(8) Excess buoyancy - 3.59 kg/m (2.41 lb/ft)
(9) Available in 30.5 m (100 ft) sections as well as special lengths

Tow Point Connection

(1) A bridle arrangement was employed to connect the boom to the bridge tow points by means of the provided end plate connectors.

Comments

(1) Lightweight, easily deployed.

ACME - O.K. CORRAL BOOM

Design Characteristics

(1) Draft - 0.15 m (6 in)
(2) Freeboard - 0.15 m (6 in)
(3) Flotation - unicellular plastic foam (Dow Ethafoam) thermal sealed into fabric 0.15 m (6 in) diameter x 1.37 m (4.5 ft) length
(4) Ballast - 0.953 cm (0.375 in) chain ballast
(5) Skirt material - "Jaton" nylon fabric coated with polyvinyl chloride, 0.79 mm (0.03 in) thick
(6) Tension member - self-tensioning boom
(7) Weight - 4.11 kg/m (2.76 lb/ft)

(8) Excess buoyancy - 13.50 kg/m (9.07 lb/ft)
(9) Available in 3.05 m (10 ft) thru 91.44 m (300 ft) sections in 3.05 m (10 ft) increments

Tow Point Connection

(1) A bridle arrangement was connected top and bottom to an end connecting plate. This then was connected to bridge tow points.

Comments

(1) Rigging and handling required 2-3 men/section and was easy to connect.

B.F. GOODRICH - SEA BOOM

Design Characteristics

(1) Draft - 0.30 m (12 in)
(2) Freeboard - 0.15 m (6 in)
(3) Flotation - continuous chambers of closed cell foam, protected by a 0.635 cm (0.25 in) PVC coating and secured at the boom ends with wooden plugs.
(4) Ballast - tubular extrusion filled with lead shot and sand
(5) Skirt material - 0.635 cm (0.25 in) thick vinyl sheet reinforced with rib-handles of urethane
(6) Tension member - self-tensioning boom
(7) Weight - 11.91 kg/m (8.0 lb/ft)
(8) Excess buoyancy - 10.42 kg/m (7.0 lb/ft)
(9) Standard length - 7.16 m (23.5 ft)

Tow Point Connection

(1) A bridle arrangement was connected to the manufacturer's provided "SEALOC" system. This consists of a piano hinge arrangement with fiberglass pins.

Comments

(1) Required 10 men/section for handling as well as crane for deployment and removal.
(2) End plates and connections were handled easily.

SLICKBAR, INC. - MARK VI BOOM

Design Characteristics

(1) Draft - 0.20 m (8 in)
(2) Freeboard - 0.17 m (6.5 in)
(3) Flotation - polyethylene foam with solid polyethylene skin

0.17 m (6.5 in) diameter x 1.27 m (4.2 ft) length
(4) Ballast - hardened lead weights
(5) Skirt material - polyester woven multifilament-fabric impregnated with PVC
(6) Tension member - 0.953 cm (0.375 in) stainless steel cable
(7) Weight - 3.82 kg/m (2.57 lb/ft)
(8) Excess buoyancy - 5.94 kg/m (3.99 lb/ft)
(9) Section length - continuous lengths from 15.2 to 152.4 m (50 ft to 500 ft)

Tow Point Connection

(1) A towline was connected to the manufacturer provided "Mark II End Set/Connector" and the bridge tow point.

Comments

(1) Easily deployed, lightweight

KEPNER - SEA CURTAIN BOOM

Design Characteristics

(1) Draft - 0.30 m (12 in)
(2) Freeboard - 0.20 m (8 in)
(3) Flotation - closed cell foam 2.44 m (8 ft) long
(4) Ballast - 0.635 cm (0.25 in) galvanized chain
(5) Skirt material - vinyl-coated nylon fabric
(6) Tension member - self-tensioning boom
(7) Weight - 3.72 - 4.46 kg/m (2.5 - 3.0 lb/ft)
(8) Excess buoyancy - 29.17 kg/m (19.6 lb/ft)
(9) Common length of section - 30.5 m (100 ft) available in lengths from 1.22 - 304.8 m (4 ft to 1000 ft)

Tow Point Connection

(1) A towline was connected to the manufacturer provided slot end connectors by means of eye bolt attachments. This then was connected to the bridge tow point.

Comments

(1) Medium weight, easily deployed

STELTNER - PACE BOOM

Design Characteristics

(1) Draft - 0.51 to 0.71 m (20-28 in)
(2) Freeboard - 0.30 m (12 in)
(3) Flotation - cured vinyl 0.30 m (12 in) diameter when inflated

(4) Ballast - non ballasted
(5) Skirt material - tear-resistant nylon
(6) Tension member - dual tension boom
(7) Weight - 6.25 kg/m (4.20 lb/ft)
(8) Excess buoyancy - 138.3 kg/m (92.9 lb/ft)
(9) Section length - 15.2 m (50 ft)

Tow Point Connection

(1) A connector bar was employed between forward and rear floats and then attached to bridge tow point by means of towline.

Comments

(1) Rotational movement of oil in interfloat area was major cause of oil loss.
(2) The sophistication of this device requires more concern with regard to rigging and different testing considerations than conventional booms (Figure C-14).
(3) This boom was considered unique and experimental in that it was newly developed and had undergone limited field application.

WHITTAKER - EXPANDI-BOOM

Design Characteristics

(1) Draft - 0.50 m (19.5 in)
(2) Freeboard - 0.28 m (12.5 in)
(3) Flotation - automatic self-inflating sections measuring 1 to 2 m (3.3 to 6.6 ft) in length
(4) Ballast - 0.476 cm (0.250 in) embedded coil chain
(5) Skirt material - oil-proof mould-impregnated, plastic-coated nylon weave
(6) Tension member - ballast chain
(7) Weight - 2.31 kg/m (1.55 lb/ft)
(8) Excess buoyancy - 44.60 kg/m (34.44 lb/ft)
(9) Section length - available in 25 m (82 ft) lengths

Tow Point Connection

(1) A towline was connected to bottom-tensioned ballast chain and bridge tow point.

Comments

(1) A vacuum pump was used to draw out flotation air.

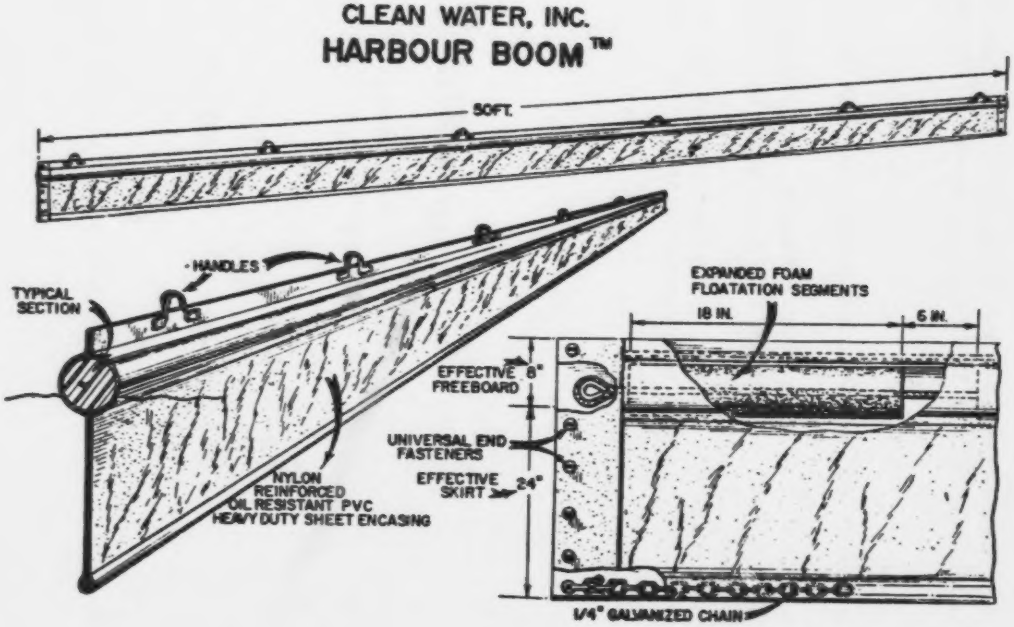
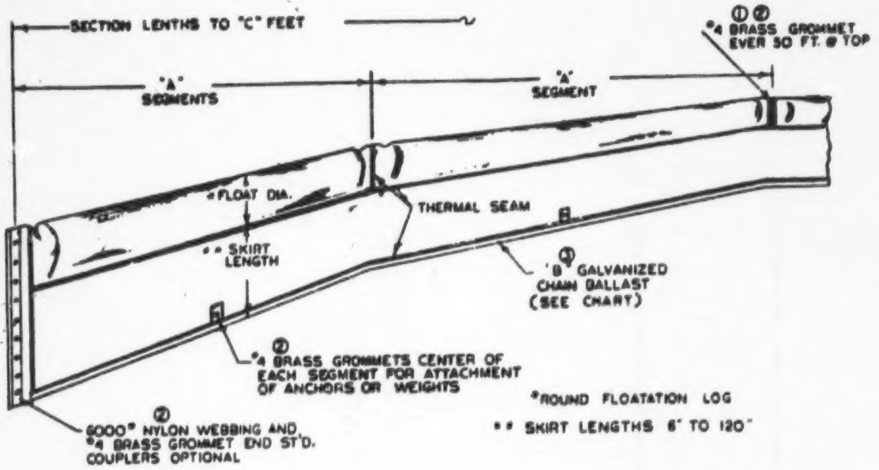
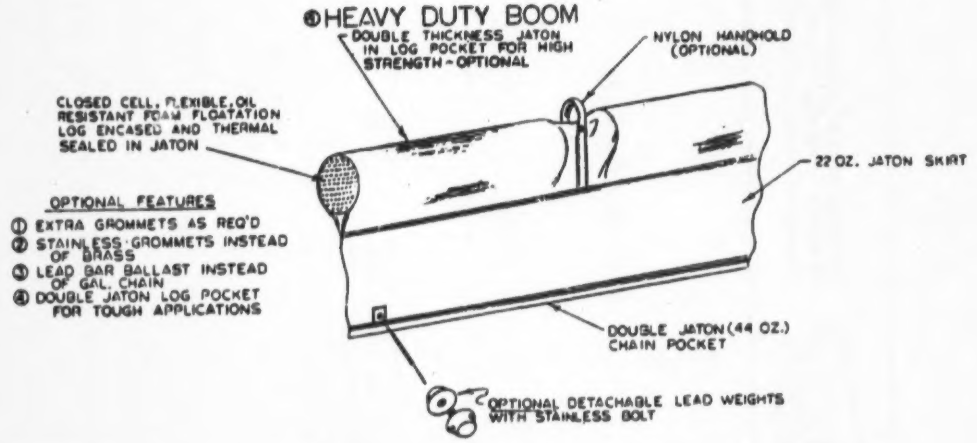

CLEAN WATER, INC.
HARBOUR BOOM™
50FT.
HANDLES
TYPICAL SECTION
NYLON REINFORCED OIL RESISTANT PVC HEAVY DUTY SHEET ENCASING
EXPANDED FOAM FLOATATION SEGMENTS
18 IN.
6 IN.
EFFECTIVE FREEBOARD 8"
UNIVERSAL END FASTENERS
EFFECTIVE SKIRT 24"
1/4" GALVANIZED CHAIN

Figure C-1. Diagram of Clean Water boom details.


SECTION LENTHS TO "C" FEET
①②
*4 BRASS GROMMET EVER 30 FT. @ TOP
"A" SEGMENTS
"A" SEGMENT
*FLOAT DIA.
THERMAL SEAM
** SKIRT LENGTH
③ 'B' GALVANIZED CHAIN BALLAST (SEE CHART)
② *4 BRASS GROMMETS CENTER OF EACH SEGMENT FOR ATTACHMENT OF ANCHORS OR WEIGHTS
*ROUND FLOATATION LOG
** SKIRT LENGTHS 6" TO 120"
② 6000* NYLON WEBBING AND *4 BRASS GROMMET END ST'D. COUPLERS OPTIONAL


④HEAVY DUTY BOOM
DOUBLE THICKNESS JATON IN LOG POCKET FOR HIGH STRENGTH - OPTIONAL
NYLON HANDHOLD (OPTIONAL)
CLOSED CELL, FLEXIBLE, OIL RESISTANT FOAM FLOATATION LOG ENCASED AND THERMAL SEALED IN JATON
22 OZ. JATON SKIRT
OPTIONAL FEATURES
① EXTRA GROMMETS AS REQ'D
② STAINLESS GROMMETS INSTEAD OF BRASS
③ LEAD BAR BALLAST INSTEAD OF GAL. CHAIN
④ DOUBLE JATON LOG POCKET FOR TOUGH APPLICATIONS
DOUBLE JATON (44 OZ.) CHAIN POCKET
OPTIONAL DETACHABLE LEAD WEIGHTS WITH STAINLESS BOLT

FLOATATION DIA.	"A" SEGMENT		"B" CHAIN		"C" SECTION TO
	STANDARD	OPTIONAL	STANDARD	OPTIONAL	
4 INCH	10 FEET	5.5 FEET	1/4 INCH	3/8 INCH	300 FEET
6 INCH	10 FEET	5.5 FEET	1/4 INCH	3/8 INCH	300 FEET
8 INCH	75 INCHS	——	1/4 INCH	3/8 INCH	300 FEET
10 INCH	75 INCHS	——	3/8 INCH	1/2 INCH	200 FEET
12 INCH	80 INCH	——	3/8 INCH	1/2 INCH	100 FEET

OPTIONAL ACCESSORIES

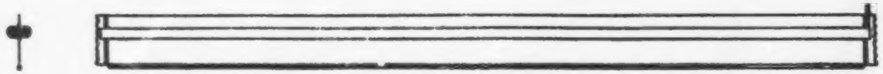
- QUICK-LATCH COUPLERS
- FLEX COUPLERS
- TOW BRIDLES
- HITCHIN-POST BULKHEAD CONNECTOR
- ADD-ON LEAD BALLAST WEIGHTS
- HAND LOOPS
- QUICK-LATCH REPAIR COUPLER
- FABRIC REPAIR KIT

ACME O K CORRAL BOOM

Figure C-2. Diagram of Acme boom details.

B.F.Goodrich seaboom™

18" SEABOOM (PFX AND SU)



The most versatile of all Seabooms, so tough it normally will last far beyond the Seaboom two year warranty. Strong and streamlined, 1,000 feet can be towed at high speed from place to place. Appropriate for harbors, bays, rivers and limited open sea use.

	18PFX	18SU
Freeboard	6"	6"
Draft	12"	12"
Weight	7.5 lbs./ft.	11 lbs./ft.
Standard Length	23.5'	23.5'
Working Strength	6,000 lbs.	8,000 lbs.
Reserve Buoyancy	7 lbs./ft.	4 lbs./ft.
Stability	Very High	Very High
Volume/Std. Length	11.2 ft.³	11.2 ft.³

Figure C-3. Diagram of B.F. Goodrich boom details.

SLICKBAR SPECIFICATIONS

SWAGED CABLE TERMINATORS
The load support cable is attached to the Slickhitch Mark II Connector through a stainless steel swaged cable terminator. This type of construction allows the end sets and cable to carry almost all of the load instead of the skirt.

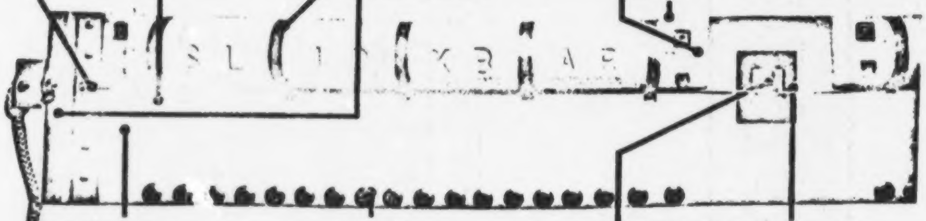
FASTENINGS
All fastenings are stainless steel.

FLOAT STRAP
Special high tensile PVC coated polyester fabric, 1" wide.

SLICKHITCH MARK II CONNECTOR
The Slickhitch Mark II Connector is extruded aluminum, anodized to exceed MIL-A-8625 (Type 2). It is designed to join sections of boom together instantly without any tools. When you want to disconnect sections, just remove the retaining pin and the halves come apart.

HARDENED FLOAT ENDS
Float ends are provided with a hard, tapered
during processing for durability and streaml

FLOATATION
4" (10 cm) or 6.5" (16.5 cm) high, bright yellow polyethylene foam. The foam is processed to impart a solid polyethylene skin over the entire surface. Ultra-violet and oxidation inhibitors are incorporated in the foam for durability and extended life.



SKIRT MATERIAL
Woven polyester fabric coated with International Orange PVC with UV inhibitors for longer life. The fabric exceeds USA FTMS 191, required to meet MIL-B-28617 (YD). Temperature range -20° F to +200°F.

BALLAST
Ballast is lead, hardened with antimony for longer life. Each weight is securely riveted to the bottom of the skirt. The amount of ballast is varied to meet individual conditions. See our price list for information about selecting ballast.

TOW ROPES

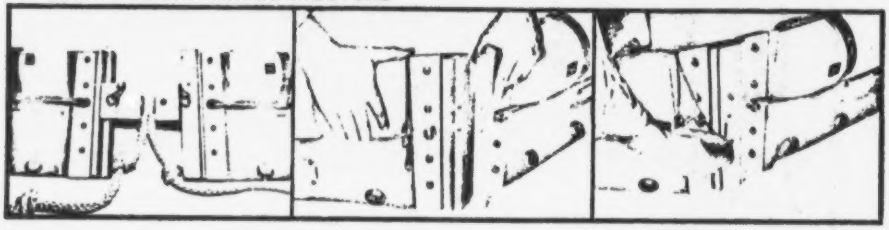
50', braided, 1/2", high tensile floating synthetic rope.

LOAD SUPPORT CABLE
Stainless steel, 7 x 19 x 1/4" dia. The load support cable supplies tension load capability in excess of 5,000 lbs. 2272 kg. During use, loads imposed on the boom are transferred to the cable through numerous attachments along the floats and at every anchor point.

ANCHOR POINTS

Anchor Points are standard every 100'. Additional anchor points are available.

MARK II SLICKHITCH CONNECTORS



I
Line up two opposite ends and remove the towing plates by pulling out the retaining pin.

II
Interlock the two halves. It is not necessary to slide the ends together from top or bottom.

III
Insert the retaining pin. For added security, both pins may be used even though only one is necessary. The Mark II Slickhitch allows 4" and 6.5" booms to be interlocked without misalignment of the load support cables or the float water line.

SLICKBAR.INC
250 PEQUOT AVENUE, P.O. BOX 139
SOUTHPORT, CT 06490 U.S.A. 203-255-2601

®Slickbar and Slickhitch are registered Trademarks of Slickbar Inc.

Slickbar Oil Booms are protected under one or more of the following Patent numbers: U.S.A. 3,146,598, 3,321,923, 3,499,290, 3,584,852, 3,983,036; United Kingdom 983,227; Canada 852,401; France 1,403,411; Italy 732,311, 866,809; Japan 588,400; Belgium 735,074. Other U.S. and foreign patents pending.

Specifications subject to change without notice.

Printed in USA 10M 573

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Figure C-4. Diagram of Slickbar boom details.

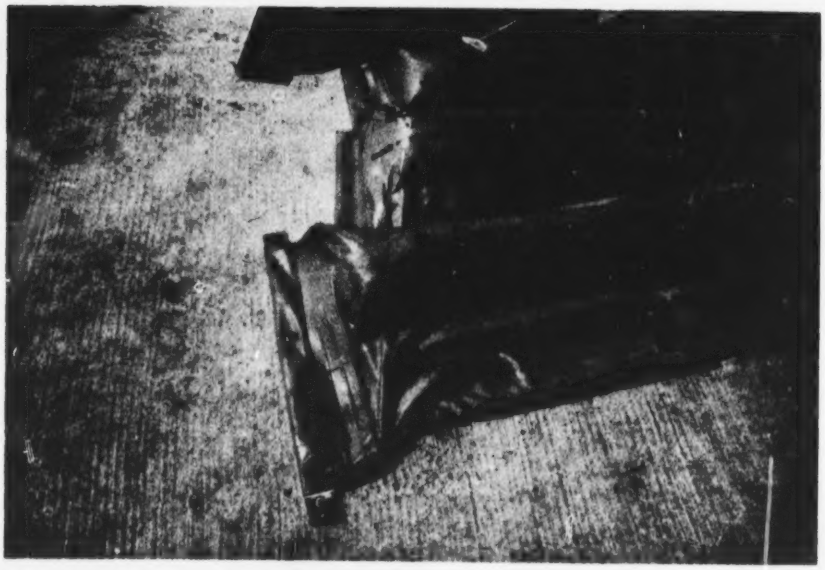

Figure C-5. Photograph of Kepner boom.

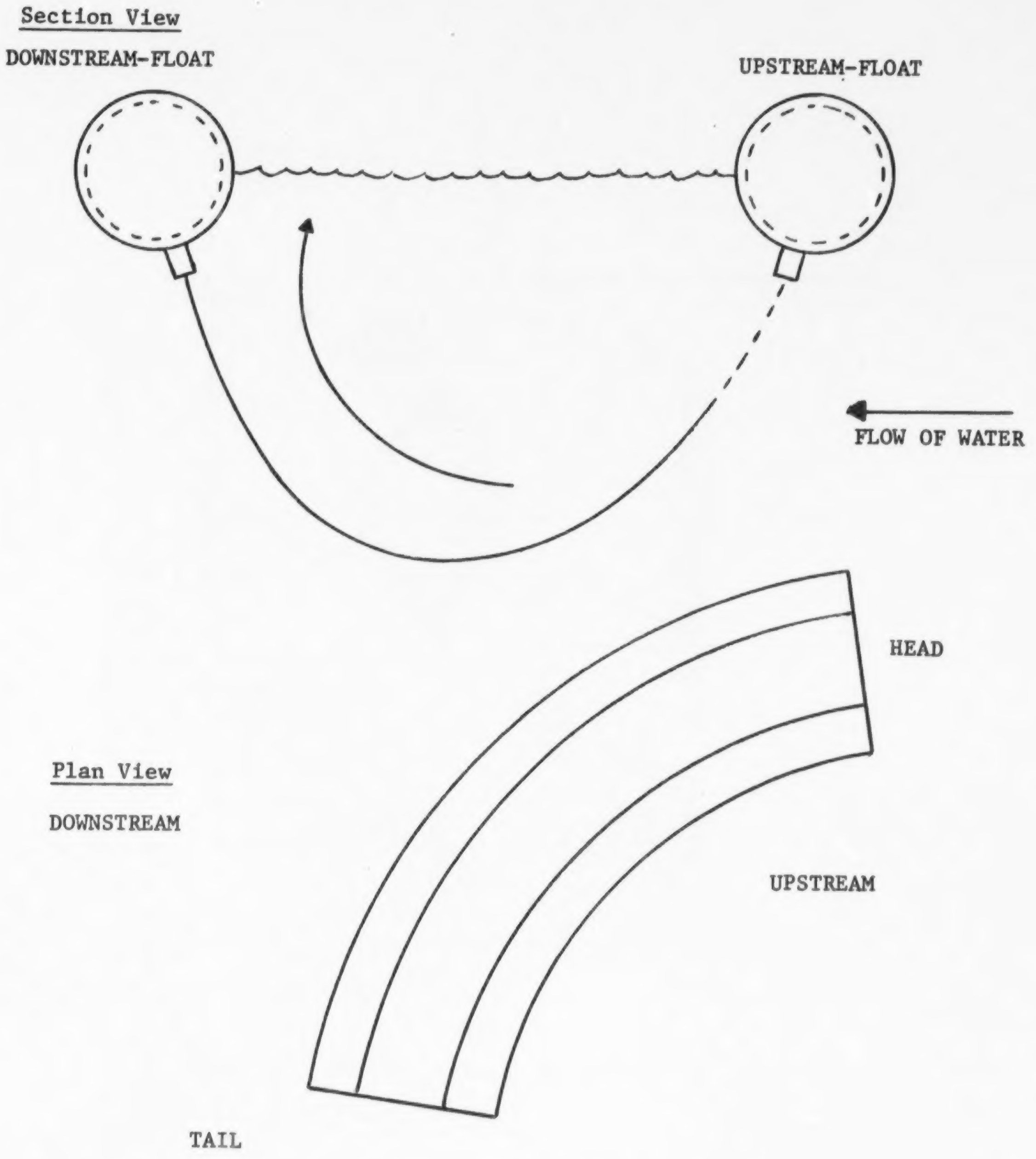
Section View
DOWNSTREAM-FLOAT
UPSTREAM-FLOAT
FLOW OF WATER
HEAD
Plan View
DOWNSTREAM
UPSTREAM
TAIL

Figure C-6. Diagram of Pace oil boom details.

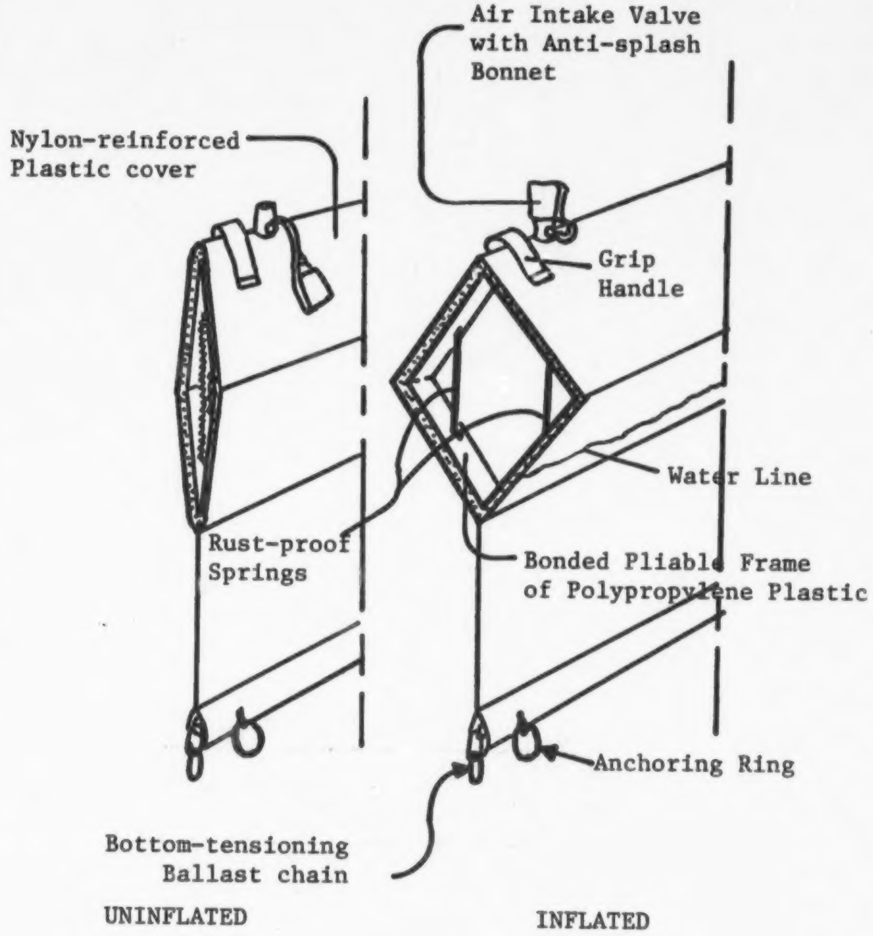
Air Intake Valve with Anti-splash Bonnet
Nylon-reinforced Plastic cover
Grip Handle
Water Line
Rust-proof Springs
Bonded Pliable Frame of Polypropylene Plastic
Anchoring Ring
Bottom-tensioning Ballast chain
UNINFLATED
INFLATED

Figure C-7. Diagram of Whittaker boom details.

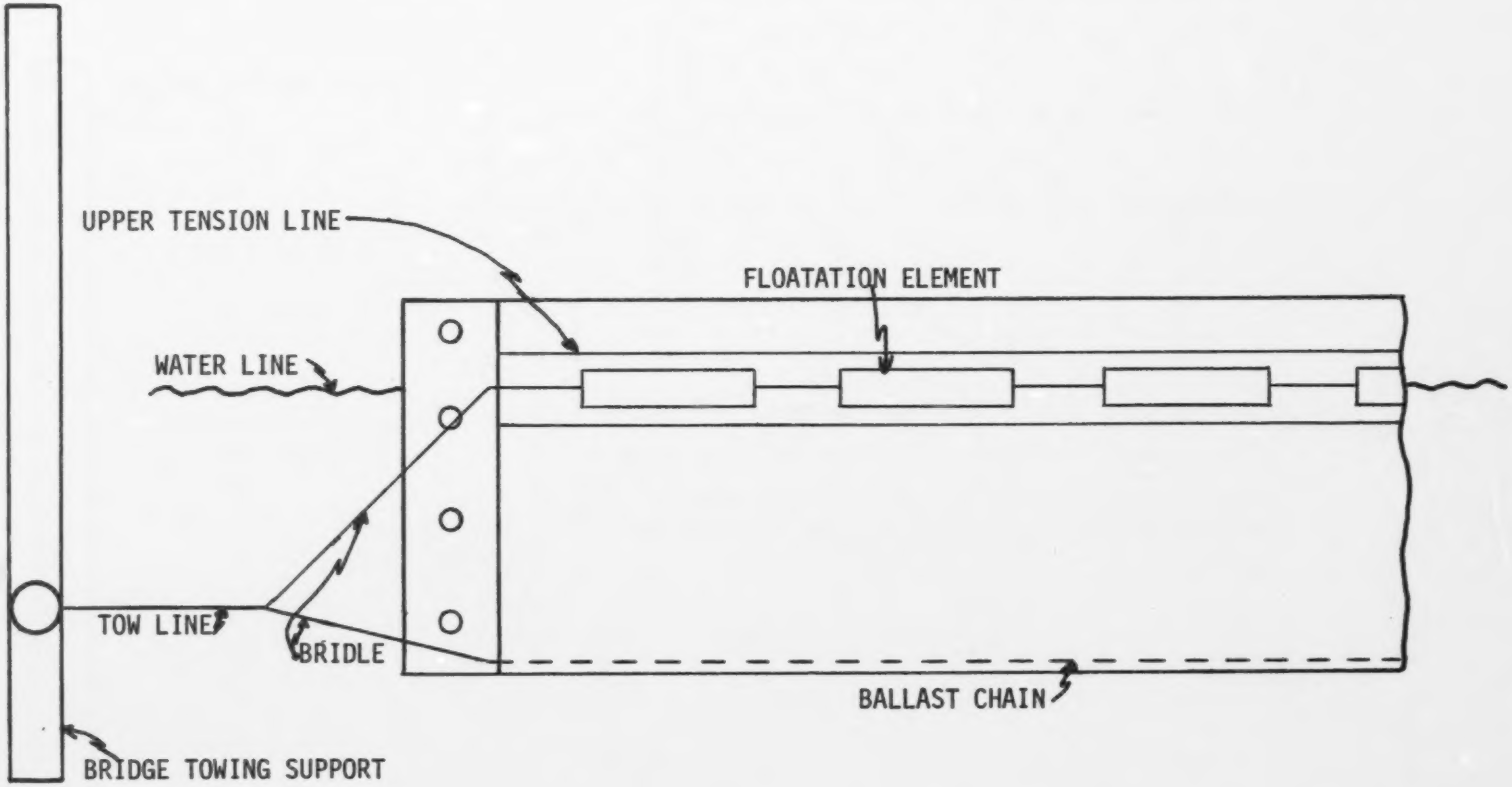
UPPER TENSION LINE
FLOATATION ELEMENT
WATER LINE
TOW LINE
BRIDLE
BALLAST CHAIN
BRIDGE TOWING SUPPORT

Figure C-8. Diagram of Clean Water boom tow point connection.

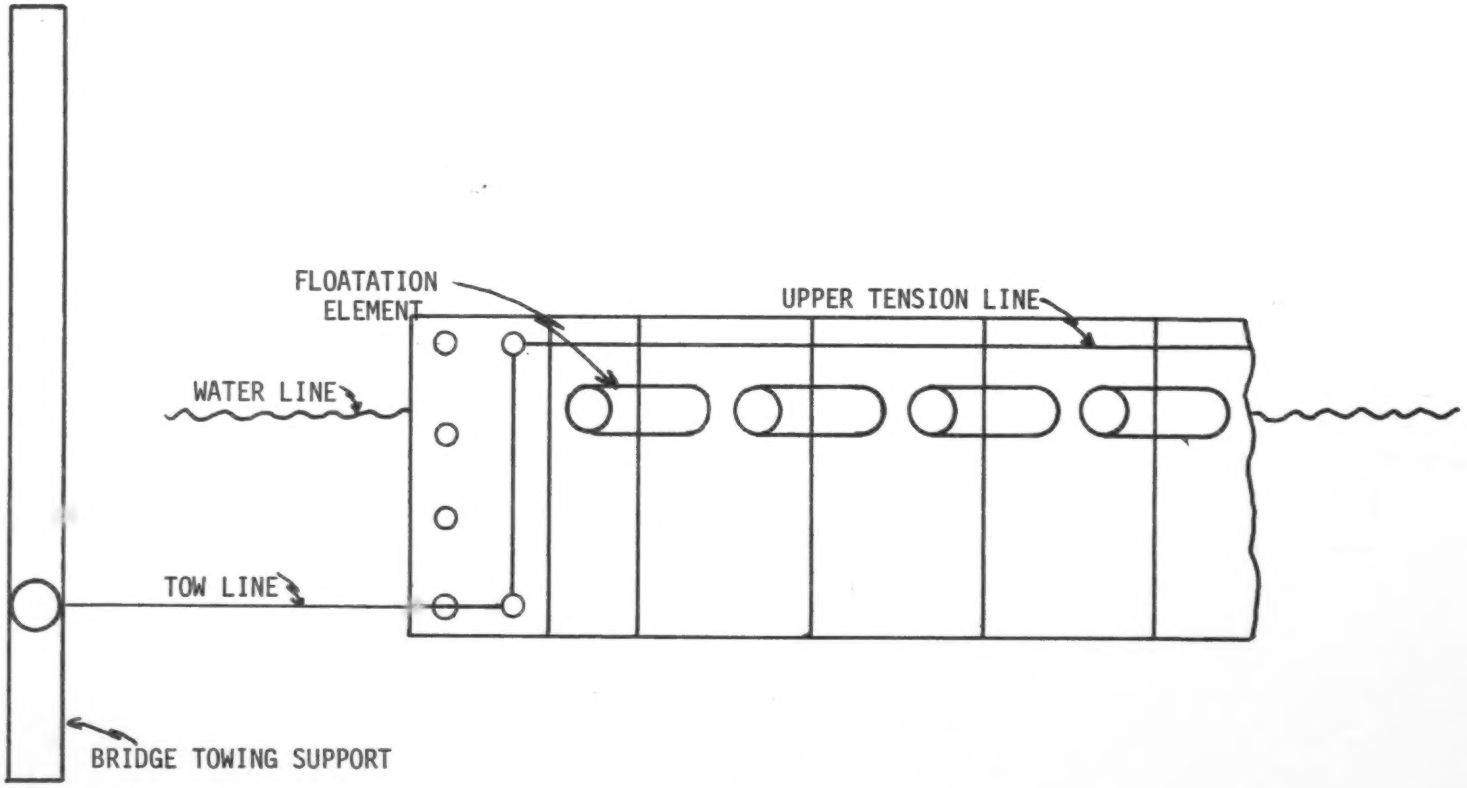
FLOATATION
ELEMENT
UPPER TENSION LINE
WATER LINE
TOW LINE
BRIDGE TOWING SUPPORT

Figure C-9. Diagram of Coastal Services boom tow point connection.

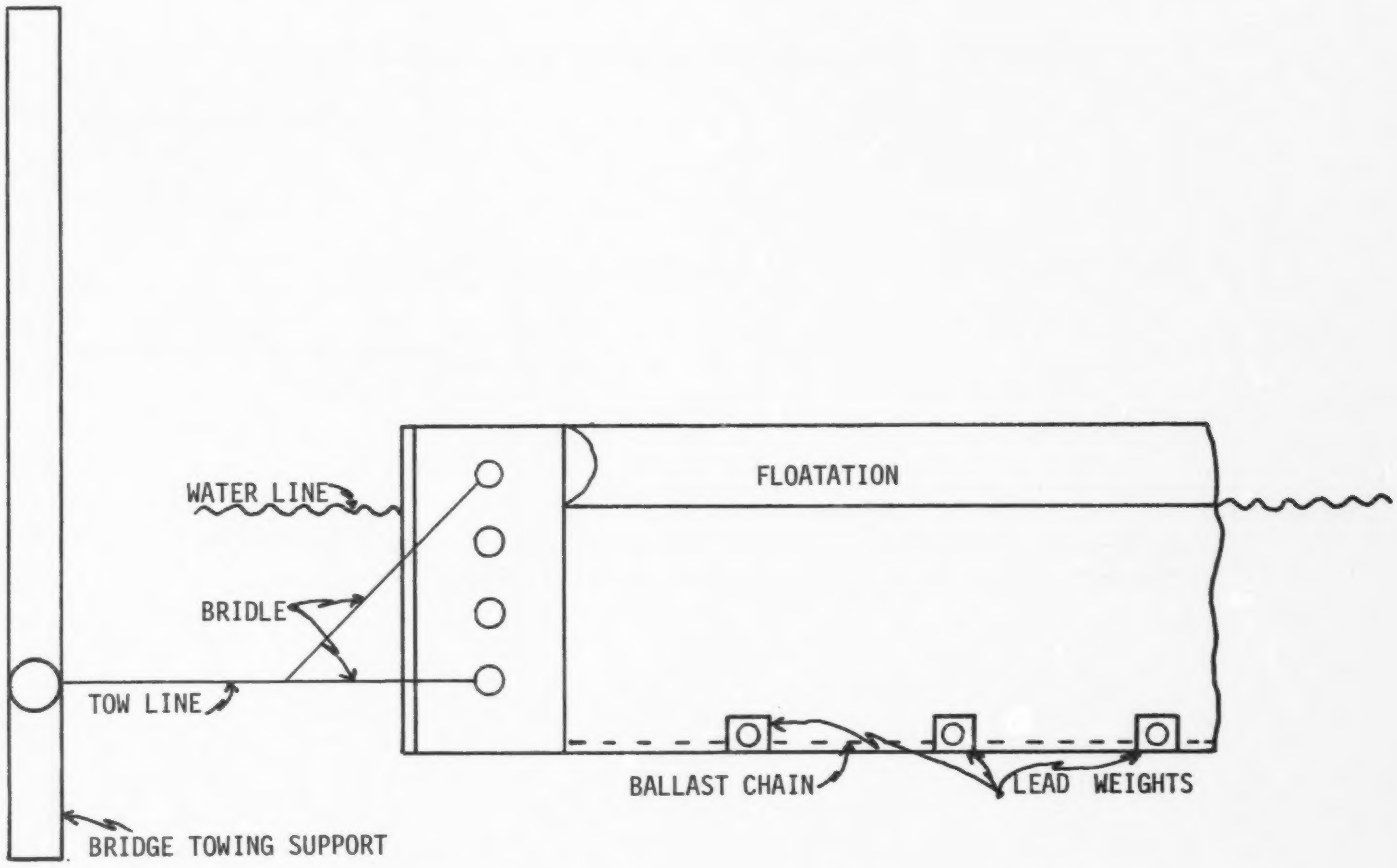
WATER LINE
FLOATATION
BRIDLE
TOW LINE
BALLAST CHAIN
LEAD WEIGHTS
BRIDGE TOWING SUPPORT

Figure C-10. Acme boom tow point connection.

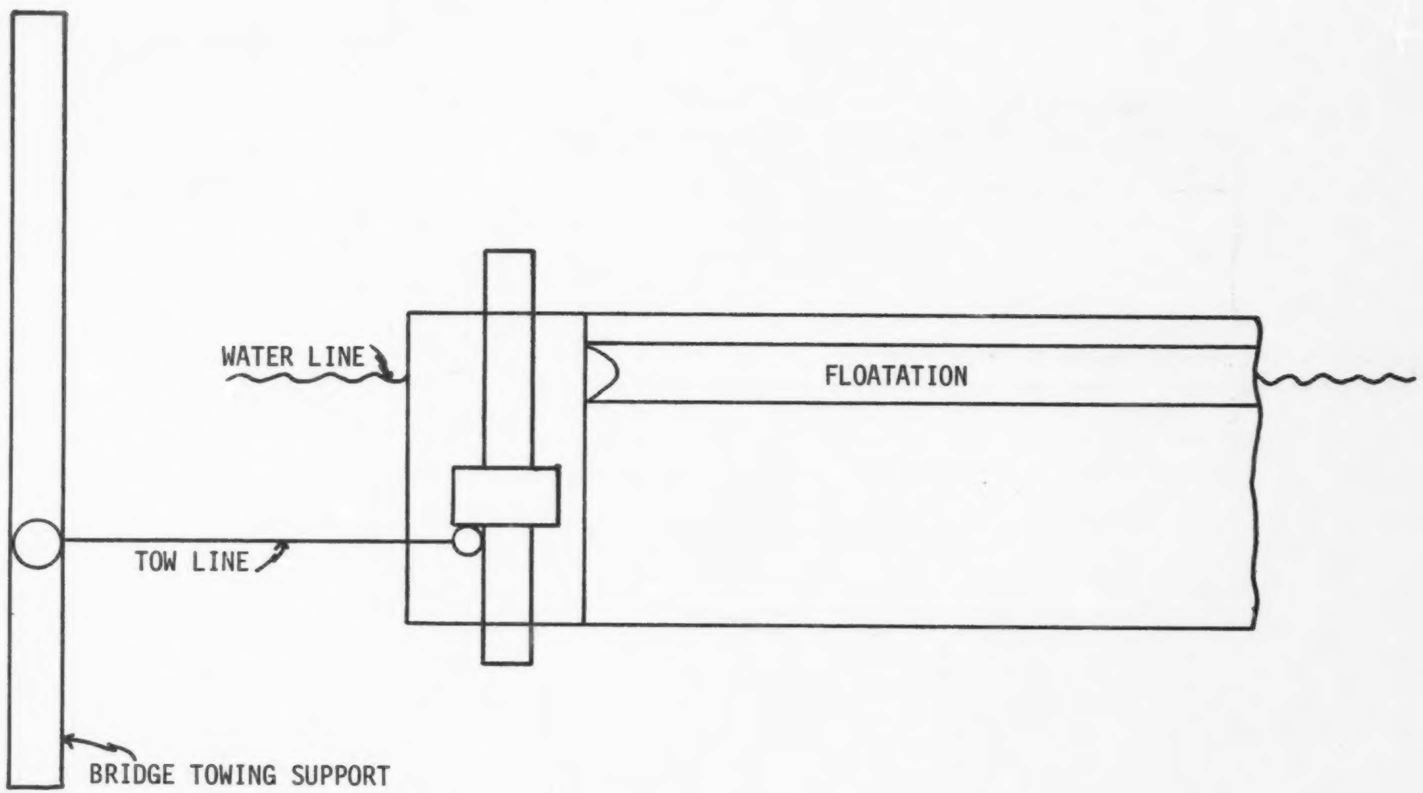
WATER LINE
FLOATATION
TOW LINE
BRIDGE TOWING SUPPORT

Figure C-11. B.F. Goodrich boom tow point connection.

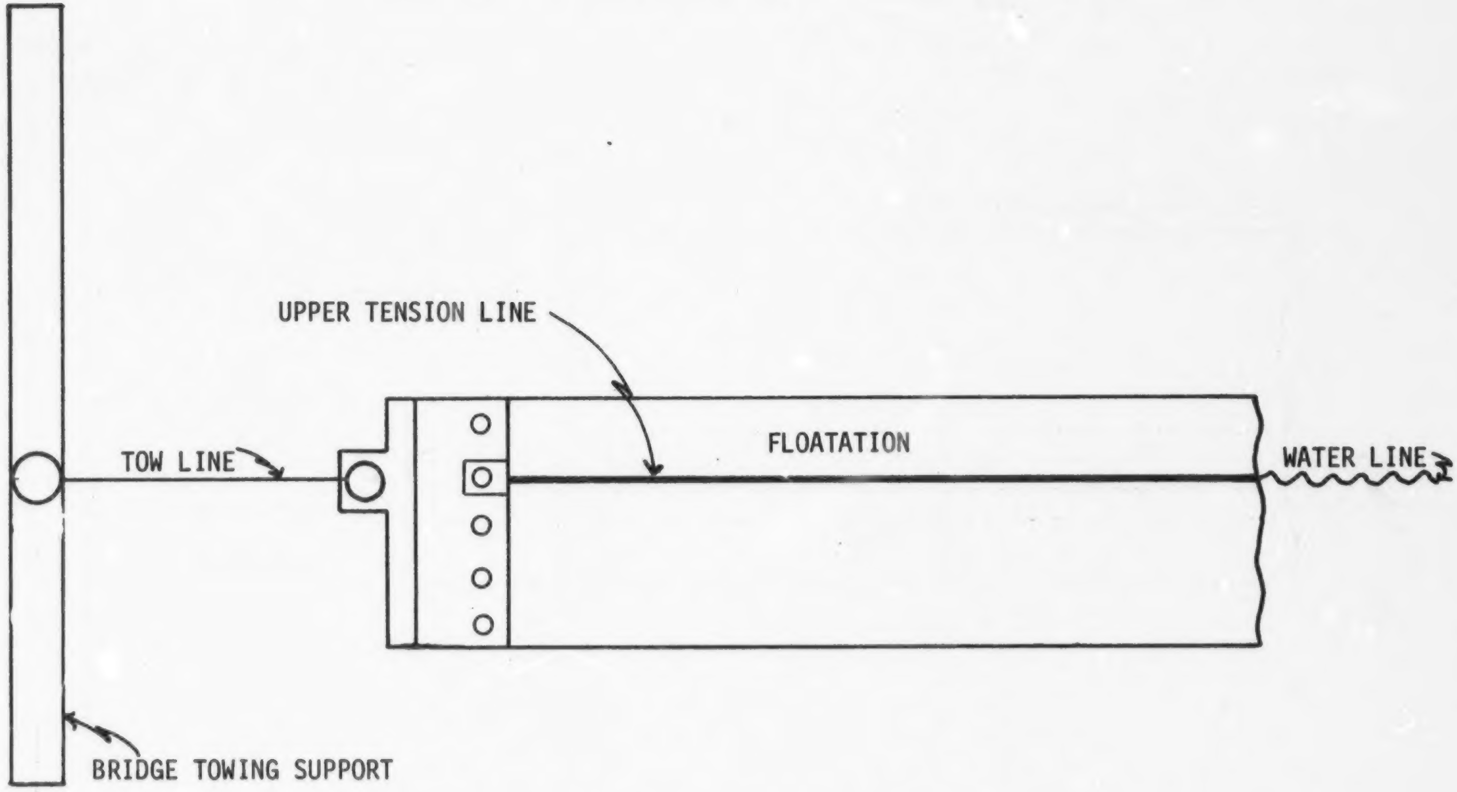
UPPER TENSION LINE
FLOATATION
TOW LINE
WATER LINE
BRIDGE TOWING SUPPORT

Figure C-12. Slickbar boom tow point connection.

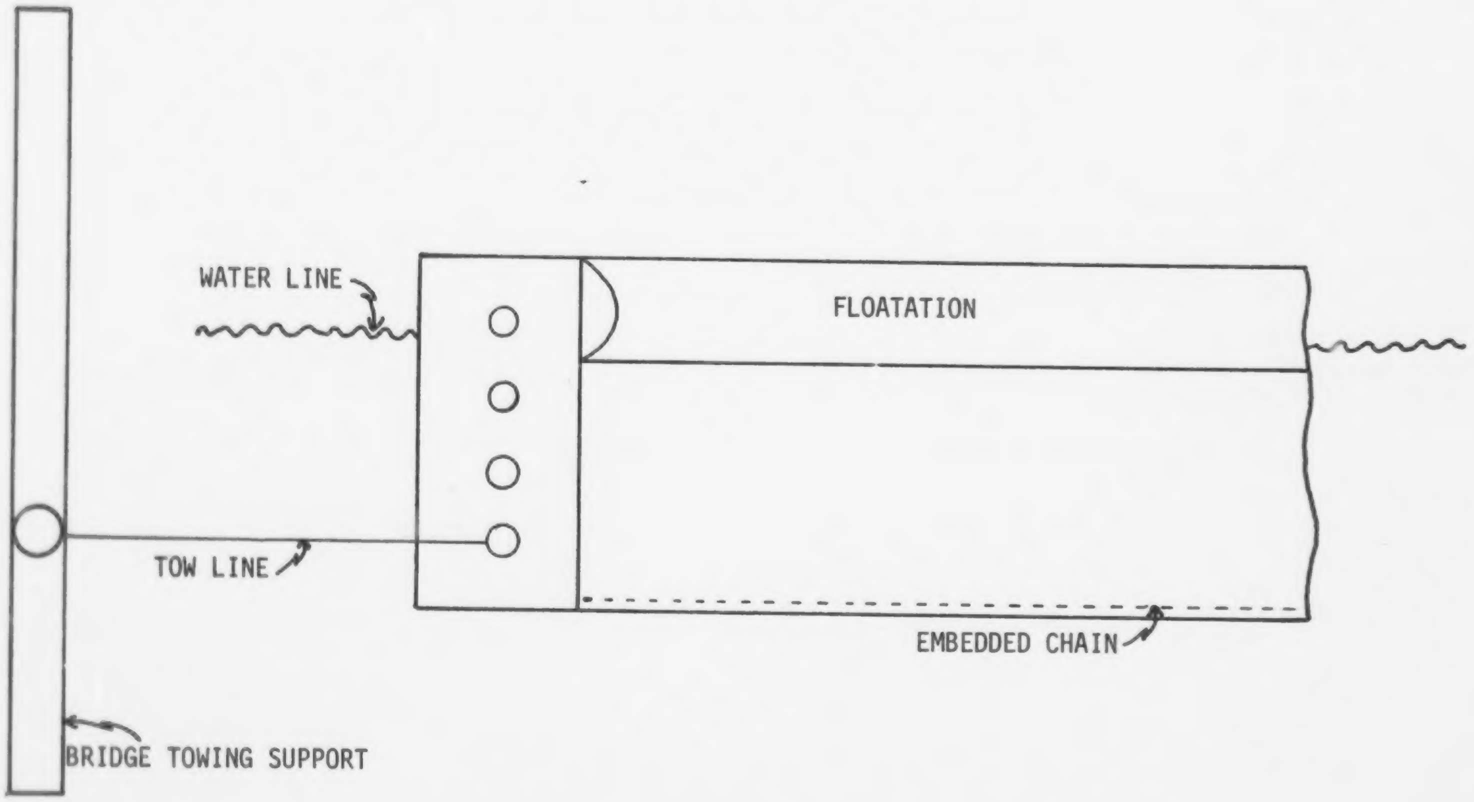
WATER LINE
FLOATATION
TOW LINE
EMBEDDED CHAIN
BRIDGE TOWING SUPPORT

Figure C-13. Kepner boom tow point connection.

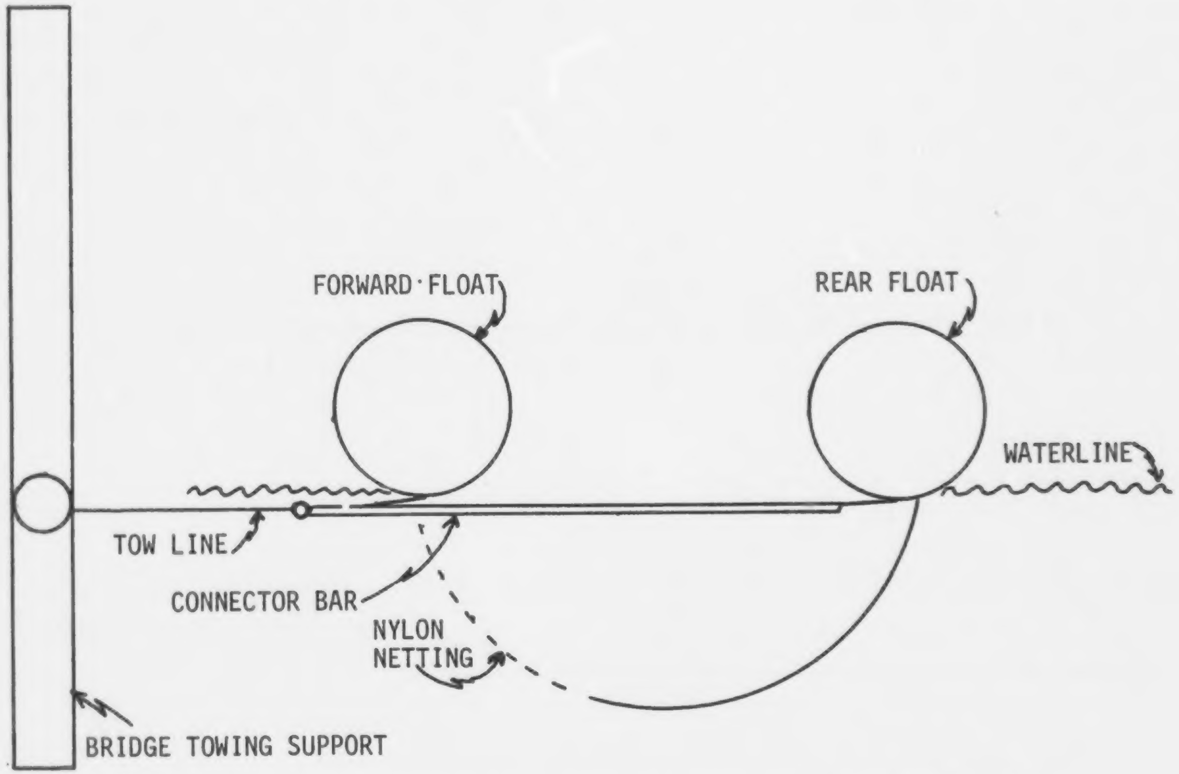
FORWARD·FLOAT
REAR FLOAT
WATERLINE
TOW LINE
CONNECTOR BAR
NYLON NETTING
BRIDGE TOWING SUPPORT

Figure C-14. Pace oil boom tow point connection.

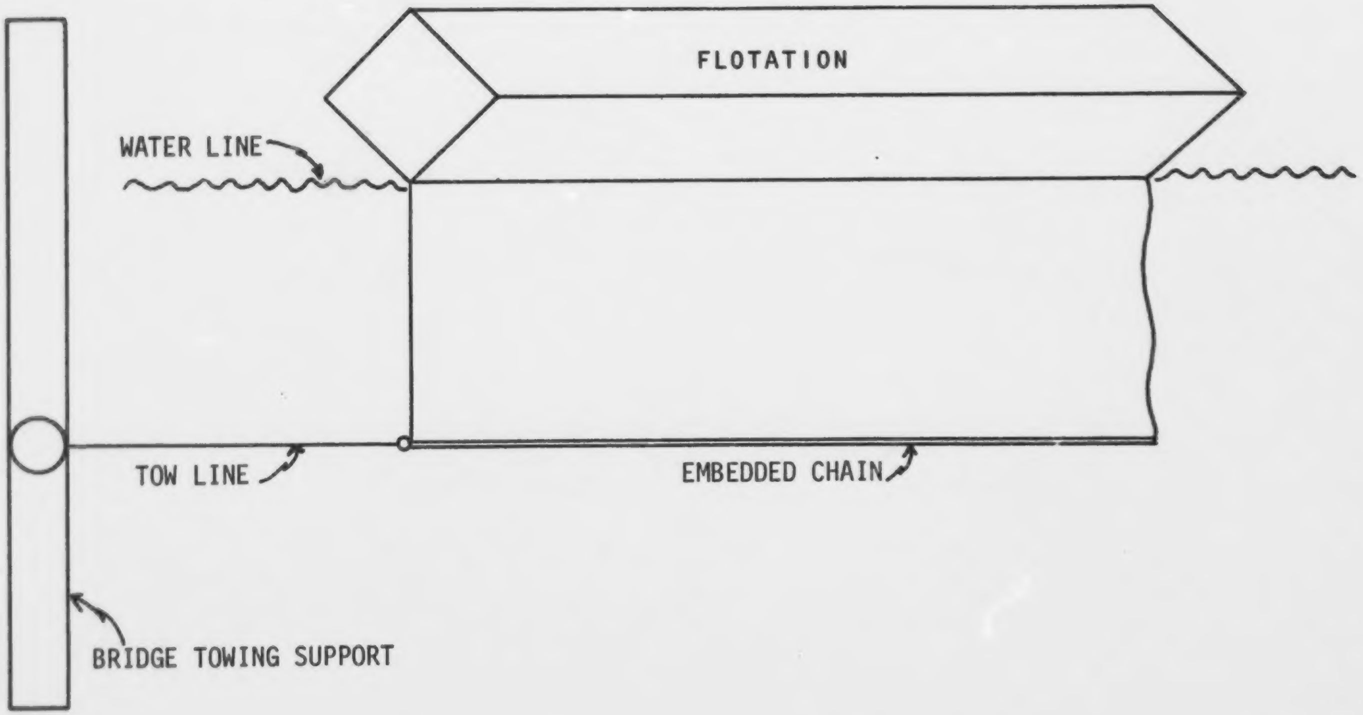
FLOTATION
WATER LINE
TOW LINE
EMBEDDED CHAIN
BRIDGE TOWING SUPPORT

Figure C-15. Whittaker boom tow point connection.

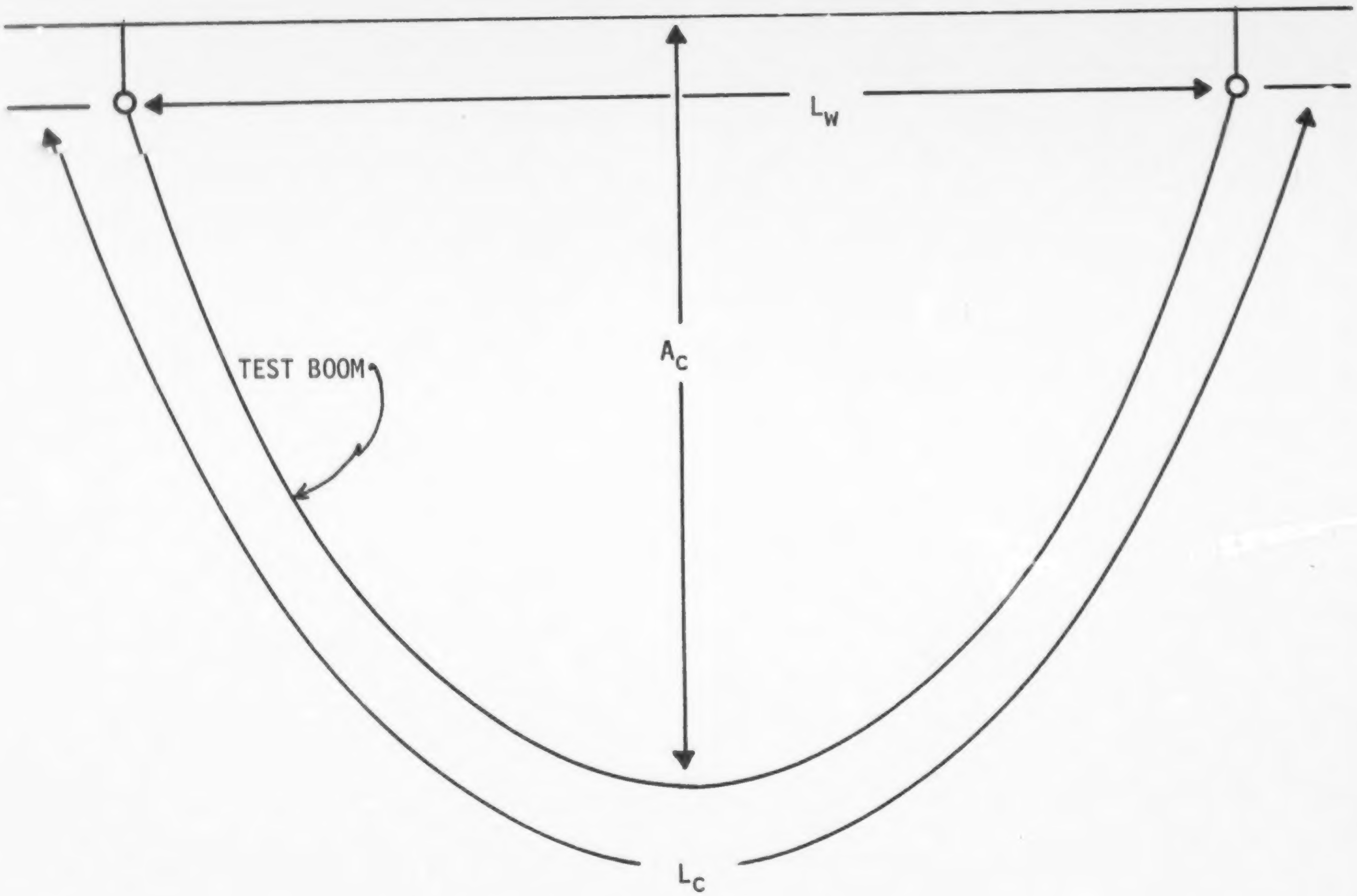
L_W
A_C
TEST BOOM
L_C

Figure C-16. Catenary rigging details.

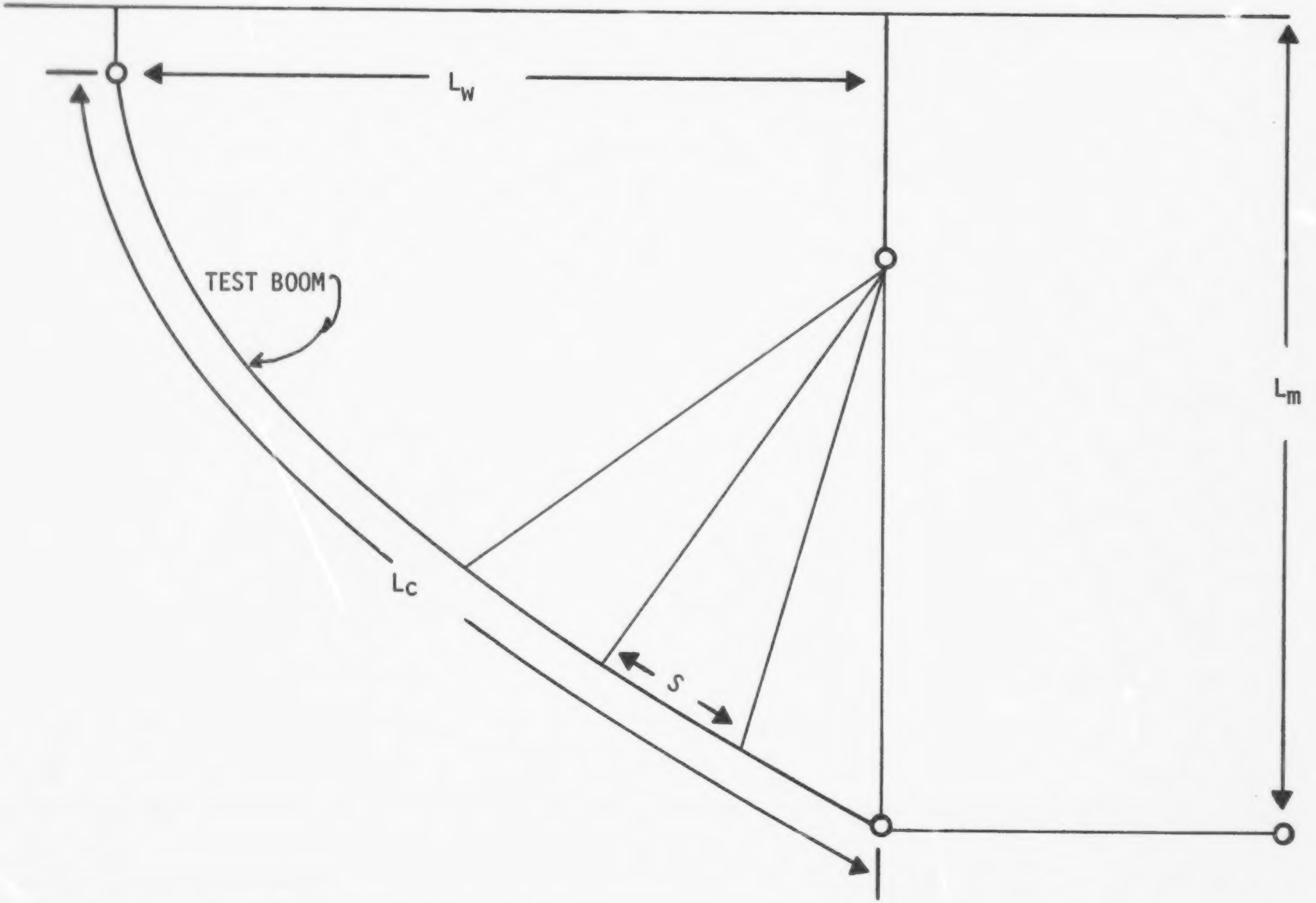
L_w
TEST BOOM
L_m
L_c
S

Figure C-17. Diversionary rigging details.

BOOM	DRAFT meters (ft)	FREEBOARD meters (ft)	WEIGHT (kg/m) (lb/ft)	NET BUOYANCY (kg/m) (lb/ft)
CLEAN WATER	0.61 (2)	0.20 (0.6)	3.04 (2.04)	4.02 (2.70)
COASTAL SERVICES	0.30 (1)	0.15 (0.5)	2.46 (1.65)	3.59 (2.41)
ACME	0.15 (0.5)	0.15 (0.5)	4.11 (2.71)	13.50 (9.07)
B. F. GOODRICH	0.30 (1)	0.15 (0.5)	11.91 (8.00)	10.42 (7.00)
SLICKBAR	0.20 (0.6)	0.17 (0.5)	3.82 (2.57)	5.94 (3.99)
KEPNER	0.30 (1)	0.20 (0.6)	4.09 (2.75)	29.17 (19.60)
PACE	0.61 (2)	0.30 (1)	6.25 (4.20)	138.25 (92.90)
WHITTAKER	0.50 (1.5)	0.29 (1.1)	2.31 (1.55)	44.60 (34.44)

Table C-1. Summary of boom design characteristics.

	Catenary						Diversionary							
Boom	L_c		L_w		A_c		L_c		L_w		L_m		S	
	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
Cleanwater	61.0	200	19.2	63	25.9	85	30.5	100	13.1	43	22.6	74	7.6	25
Coastal Services (tests 15 → 23)*	61.0	200	19.2	63	25.9	85	30.5	100	12.5	41	22.9 (26.5)	75 (87)*	7.6	25
Acme	59.7	195	18.6	61	28.3	93	29.9	98	12.5	41	28.0	92	7.6	25
B.F. Goodrich	56.7	185	18.6	61	25.9	85	29.3	96	12.5	41	25.9	85	8.5	28
Slickbar	61.0	200	19.2	63	29.0	95	30.5	100	12.5	41	29.3	96	7.6	25
Kepner	61.0	200	18.6	61	28.7	94	29.3	96	12.5	41	27.7	90	7.0	23
Pace	30.5	100	18.3	60	10.7	35	30.5	100	12.5	41	12.8	42	---	---
Whittaker	52.6	172	19.2	63	24.7	81	27.4	90	12.5	41	24.3	80	7.6	25

Table C-2. Summary of rigging specifications.

APPENDIX D

TEST EQUIPMENT

SKIMMERS

The following section of the manual describes the individual skimmer systems tested. Individual systems are detailed in the following manner:

Manufacturer - Name of system
Design characteristics
Pump data

Diagrams and photographs are given separately following the above details in this appendix.

Certain materials are reprinted courtesy of the individual manufacturers.

SLICKBAR, INC. - 1 INCH RIGID MANTA RAY (NO. 1)

Design Characteristics

(1) Size - 0.03 m (1 in) opening by 1.22 m (4 ft) diameter
(2) Weight - 11.3 kg (25 lb)

Pump

(1) Type - twin diagram, self-priming
(2) Hose - 0.10 m (4 in) I.D. floating suction hose, 3.05 m (10 ft) lengths
(3) Capacity - 1.1 x 10^{-2} m^3/sec (178 gpm)

SLICKBAR, INC. - 1 INCH FLEXIBLE MANTA RAY (NO. 2)

Design Characteristics

(1) Size - 0.03 m (1 in) opening by 1.52 m (5 ft) diameter
(2) Weight - 26.3 kg (58 lb)

Pump

(1) Type - twin diaphragm, self-priming
(2) Hose - 0.10 m (4 in) I.D. floating suction hose, 3.05 m (10 ft) lengths
(3) Capacity - 1.10 x 10^{-2} m^3/sec (178 gpm)

SLICKBAR, INC. - 0.5 INCH FLEXIBLE MANTA RAY (NO. 3)

Design Characteristics

(1) Size - 0.01 m (0.5 in) opening by 1.52 m (5 ft) diameter
(2) Weight - 26.3 kg (58 lb)

Pump

(1) Type - twin diaphragm, self-priming
(2) Hose - 0.10 m (4 in) I.D. floating suction hose, 3.05 m (10 ft) lengths
(3) Capacity - 1.1 x 10^{-2} m^3/sec (178 gpm)

SLICKBAR, INC. - ALUMINUM SKIMMER (NO. 4)

Design Characteristics

(1) Size - 0.05 m (2 in) opening by 1.22 m (4 ft) wide
(2) Weight - 31.8 kg (70 lb)

Pump

(1) Type - twin diaphragm, self-priming
(2) Hose - 0.10 m (4 in) I.D. floating suction hose, 3.05 m (10 ft) lengths
(3) Capacity - 1.1 x 10^{-2} m^3/sec (178 gpm)

ACME - FLOATING SAUCER SK-39T

Design Characteristics

(1) Size - 1.17 m (46 in) diameter
(2) Weight - 62.6 kg (138 lb) with gasoline power

Pump

(1) Type - axial flow
(2) Hose - 0.10 m (4 in) I.D.
(3) Capacity - 1.3 x 10^{-3} m^3/sec (200 gpm)

V.I. KOMARA - MINISKIMMER

Design Characteristics

(1) Size - maximum width - 1.16 m (46 in); height - 0.51 m (20 in)
(2) Weight - 52 kg (115 lb)

Pump

(1) Type - double acting induced flow

(2) Hose - 0.04 m (1.5 in) I.D.
(3) Capacity - 3.2×10^{-3} m^3/sec (50 gpm)

COASTAL SERVICES - SLURP

Design Characteristics

(1) Size - 0.93 m (36.8 in) length
(2) Weight - 28 kg (60 lb)

Spate Pump

(1) Type - single acting diaphragm
(2) Hose - 0.04 m (1.5 in) I.D. suction hose; 0.08 m (3 in) I.D. discharge hose
(3) Capacity - 3.2×10^{-3} m^3/sec (50 gpm)

Homelite Pump

(1) Type - single acting diaphragm
(2) Hose - 0.04 m (1.5 in) I.D. suction hose; 0.05 m (2 in) I.D. discharge hose
(3) Capacity - 2.0×10^{-3} m^3/sec (32 gpm)

Coastal Services Pump

(1) Type - centrifugal
(2) Hose - 0.04 m (1.5 in) I.D.
(3) Capacity - 2.1×10^{-3} m^3/sec (33 gpm)

I.M.E. - SWISS OELA III

Design Characteristics

(1) Size - height - 0.39 m (15.25 in)
(2) Weight - 49.9 kg (110 lb)

Pump

(1) Type - single acting diaphragm
(2) Hose - 0.05 m (2 in) I.D.
(3) Capacity - 2.0×10^{-3} m^3/sec (32 gpm)

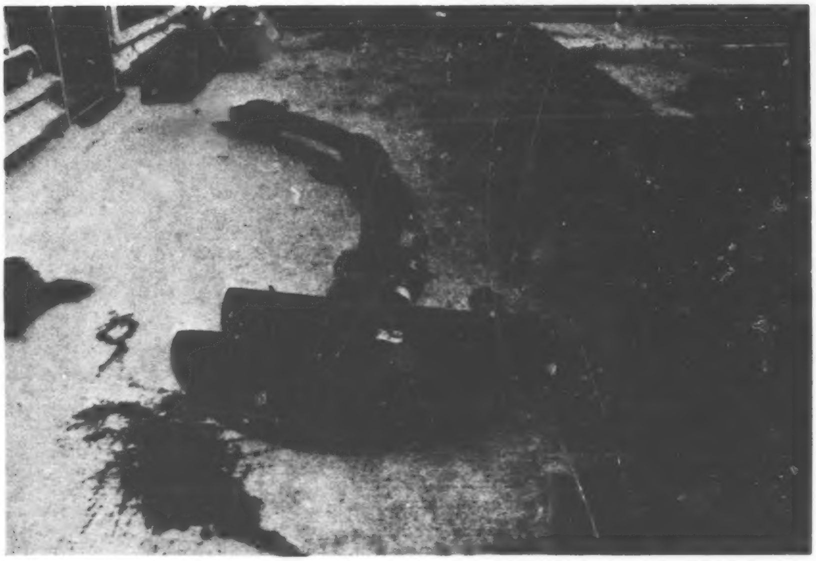

Figure D-1. Photograph of Slickbar skimmer no. 1.

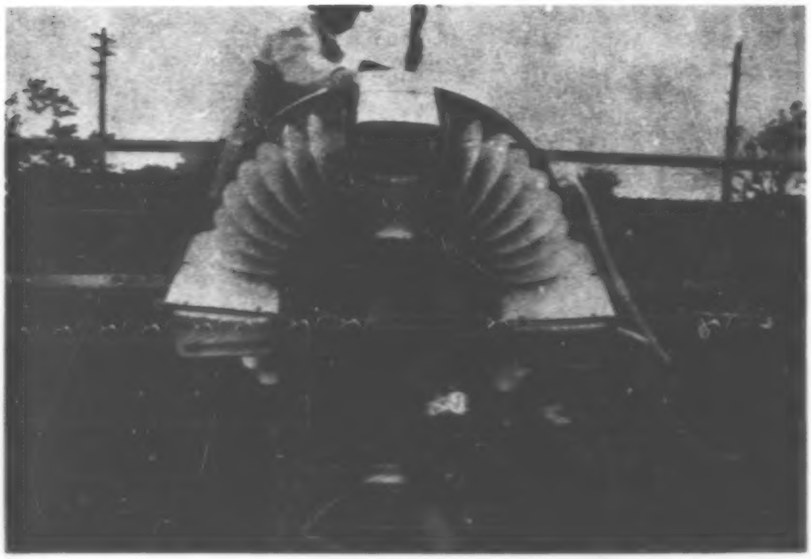

Figure D-2. Photograph of V.I. Komara miniskimmer.

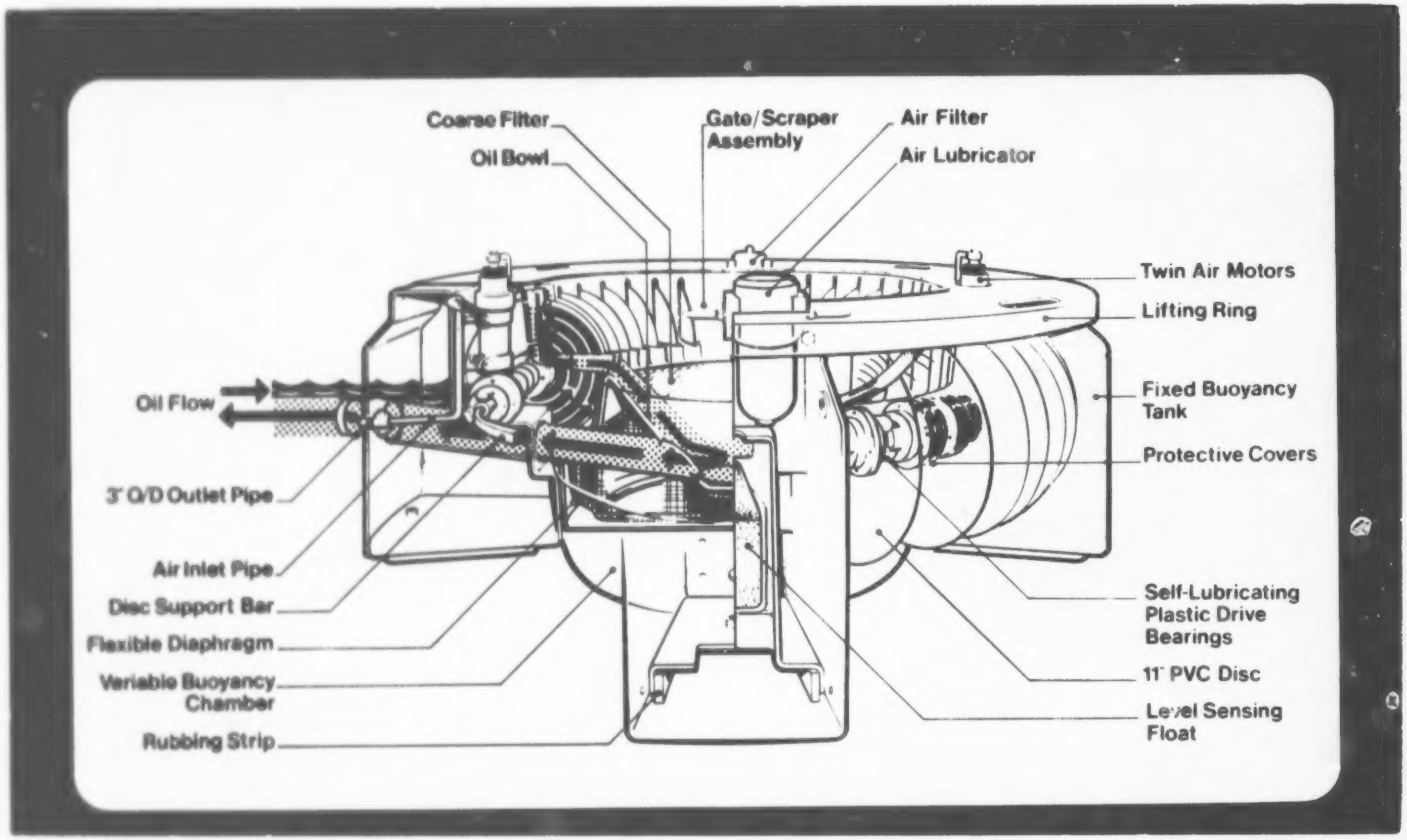
Coarse Filter
Oil Bowl
Gate/Scraper Assembly
Air Filter
Air Lubricator
Twin Air Motors
Lifting Ring
Fixed Buoyancy Tank
Protective Covers
Oil Flow
3" O/D Outlet Pipe
Air Inlet Pipe
Disc Support Bar
Flexible Diaphragm
Variable Buoyancy Chamber
Rubbing Strip
Self-Lubricating Plastic Drive Bearings
11" PVC Disc
Level Sensing Float

Figure D-3. V.I. Komara miniskimmer details.

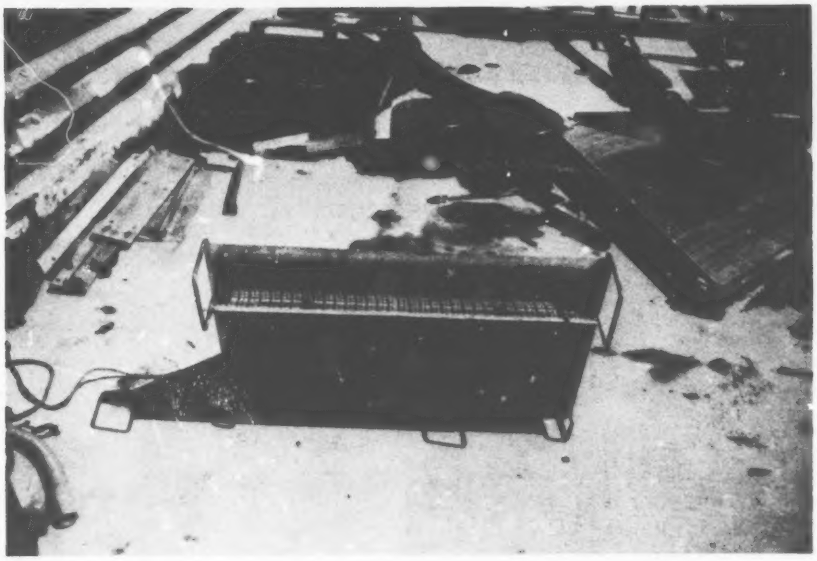

Figure D-4. Photograph of Coastal Services skimmer.

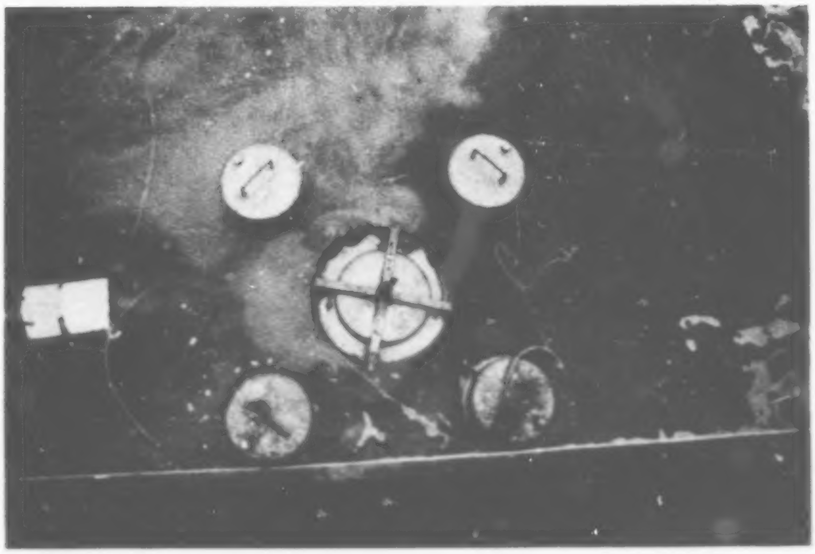

Figure D-5. Photograph of I.M.E. skimmer.

APPENDIX E

TEST RESULTS

BOOMS

The following appendix includes raw data compiled from individual test runs. The tables include:

Test identification
Test fluids' properties
Ambient conditions
Oil slick characteristics
Tow speed
Wave characteristics
Performance measurements

Test fluids' properties represent physical characteristics of pre-test samples taken from the bridge storage tanks.

Failure is represented as follows:

SU = submarine failure
SP = splashover failure
SH = shedding or entrainment-type failure
PL = planing failure
TC = tow point connection failure
NO = failure not observed through this range of tow speed

Table E-1. Test results - Clean Water boom.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec. RANGE		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm					HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
4/17	1345	1							15	2.2	W					.36-.51		0	0	∞		.51+	NO	
4/17	1424	2							15	2.2	W					.51-.81		0	0	∞		.79	SU	
4/17	1445	3							17	2.2	NW					.76-.89		0	0	∞		.79	SU	
4/17	1455	4							17	2.2	NW					0 -.76		0.3	22.9	6.0		.66	SU	
4/17	1505	5							17	2.2	NW					0 -.61		0.6	9.1	3.0		.46	SU	
4/17	1535	6							17	2.2	NW					0 -.76		0.3	13.7	4.0		.66	SU	
4/17	1600	7							18	2.2	NW					0 -.25		0.3	2.7	1.5		0	SP	
4/18	1330	8	Lube	20	1068	33.6		.915	17	8.0	SE	1.14	2.0			0 -.66		0.3	13.7	4.0		.61	SH	
4/18	1430	9	Lube	20	1068	33.6		.915	17	7.0	SE	1.51	2.0			0 -.41		0.6	9.1	3.0		.41	SH	
4/22	1004	10	Lube	20	1718	32.4		.915	12	3.0	E	1.33	2.0			0 -.61		0	0	∞		.61	SH	
4/22	1400	11	Lube	20	1994	35.9		.915	12	4.0	SW	1.36	2.0			0 -.66		0.3	13.7	4.0		.61	SH	

Table E-1 (continued).

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
4/23	1115	12							10	7.0	SE					.35-.66		0	0	∞		.61	SU	
4/23	1145	13							10	7.0	SE					.46-.61		0.3	13.7	4.0		.51	SP	
4/23	1300	14							12	8.8	SE					.46-.61		0.3	22.9	6.0		.51	SP	
4/23	1314	15							12	8.8	SE					.25-.46		0.6	9.1	3.0		.25	SP	
4/23	1345	16							15	8.8	SE					.15-.25		0.3	2.7	1.5		0	SP	
4/23	1400	17	Lube	26	405	31.7		.915	15	6.7	SE	1.06	2.0			0 -.56		0	0	∞		.44	SH	
4/23	1530	18	Lube	30	345	34.7		.915	16	4.5	S	1.56	2.0			0 -.46		0.3	13.7	4.0		.46	SH	
4/24	1030	19	Lube	30	345	34.7		.915	23	4.5	SW	1.53	2.0			0 -.25		0.6	9.1	3.0		.25	SP	
5/31	1145	109	Lube	39	238	31.5		.912	24	1.3	SE	1.32	2.0			0 -.51		0.3	2.7	1.5		0	SP	

Table E-2. Test results - Coastal Services boom.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
4/24	1500	1							21	2.2	SE					.25-.66		0	0	∞		.51	SU	
4/24	1630	2							21	2.2	SE					.25-.51		0.3	22.9	6.0		.41	SU	
4/24	1640	3							21	4.5	SW					.25-.46		0.6	9.1	3.0		.36	SU	
4/24	1715	4							21	4.5	SW					.25-.36		0.3	13.7	4.0		.36	SU	
4/24	1745	5							20	1.8	SW					0 -.25		0.3	2.7	1.5		0	SP	
4/25	1030	6	Lube	36	223	30.6		.915	17	2.2	E	1.53	2.0			0 -.51		0	0	∞		.46	SH	
4/25	1245	7	Lube	35	227	31.5		.915	20	2.2	E	1.52	2.0			0 -.30		0.6	9.1	3.0		.30+	NO	
4/25	1310	F1	Lube	35	227	31.5		.915	21	0.9	E	1.52	2.0			0 -.51		0	0	∞		.46	SH	
4/25	1435	8	Lube	30	227	31.5		.915	21	2.2	SE	1.33	2.0			0 -.36		0.6	9.1	3.0		.36	SH	
4/25	1600	9	Lube	35	245	32.5		.915	18	2.2	SE	1.34	2.0			0 -.36		0.3	13.7	4.0		.36	SH	

Table E-2 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec. RANGE		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm					HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
4/26	1015	10							15	6.7	NW					.36-.56		0	0	∞		.51	SU	
4/26	1025	11							15	6.7	NW					.25-.51		0.3	13.7	4.0		.46	SU	
4/26	1115	12							12	4.5	NW					0 -.41		0.3	2.7	1.5		0	SP	
4/26	1145	13							12	4.5	NW					.25-.46		0.3	22.9	6.0		.41	SU	
4/26	1150	14							12	4.5	NW					.25-.51		0.6	9.1	3.0		.41	SU	
4/28	1125	15							12	2.7	W					.36-.51		0	0	∞		.48	SU	
4/28	1130	16							13	2.7	W					.25-.46		0.6	9.1	3.0		.41	SU	
4/28	1145	17							14	2.7	W					.25-.46		0.6	22.9	6.0		.41	SU	
4/28	1310	18							16	4.5	W					.25-.51		0.3	13.7	4.0		.48	SU	
4/28	1200	19							15	4.5	W					0 -.25		0.3	2.7	1.5		.25	SP	
4/28	1330	20	Lube	32	324	32.5		.915	16	4.5	W	1.32	2.0			0 -.46		0	0	∞		.43	SH	

Table E-2 (continued).

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
												DIVERSIONARY												
4/28	1500	21	Lube	30	385	32.4		.915	16	4.5	W	1.32	2.0			0 -.46		0.3	13.7	4.0		.46	SH	
4/29	1015	22	Lube	32	305	32.6		.915	11	5.4	E	1.32	2.0			0 -.41		0.3	22.9	6.0		.41	SH	
4/29	1230	23	Lube	32	329	32.5		.915	11	5.4-8	E	1.32	2.0			0 -.38		0.6	9.1	3.0		.38	SH	

Table E-3. Test results - Acme boom.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
4/29	1700	24							10	6.7	E					0-.51		0	0	∞		.43	PL	
4/29	1710	25							10	6.7	E					0-.51		0.6	9.1	3.0		.43	PL	
4/29	1725	26							10	6.7	E					0-.51		0.3	22.9	6.0		.46	PL	
4/29	1735	27							10	6.7	E					0-.25		0.3	2.7	1.5		0	SP	
4/29	1745	28							10	4.5	E					0-.51		0.3	13.7	4.0		.46	PL	
4/30	1230	29	Lube	32	406	32.4		.915	12	4.5	E	1.32	2.0			.25-.51		0	0	∞		.41	SH	
4/30	1430	30	Lube	30	297	32.5		.915	13	4.5	E	1.33	2.0			.25-.51		0.3	13.7	4.0		.41	SH	
4/30	1630	31	Lube	30	297	32.5		.915	17	4.5	E	1.33	2.0			.25-.51		0.6	9.1	3.0		.41	SH	

Table E-3 (ontinued).

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
CATENARY																								
5/2	1611	33							15	2.7	SE					.25-1.12		0	0	∞		1.09	FL	
5/2	1630	34							15	2.7	SE					.25-1.02		0.3	13.7	4.0		.74	FL	
5/2	1655	35							15	2.7	SE					0-.25		0.3	2.7	1.5		0	SP	
5/2	1723	36							15	2.2	SE					.25-.56		0.6	9.1	3.0		.48	SP	
5/2	1740	37							15	2.2	SE					.25-1.27		0.3	22.9	6.0		.89	SP	
5/1	1330	32	Lube	49	164	30.1		.915	12	1.8	SE	1.32	2.0			0-.41		0.3	13.7	4.0		.38	SH	
5/3	1045	38	Lube	21	1626	31.2		.915	15	0.4	W	1.35	2.0			0-.51		0	0	∞		.43	SH	
5/3	1300	39	Lube	35	425	31.1		.915	16	0.4	S	1.32	2.0			0-.51		0.6	9.1	3.0		.43	SH	
5/3	1430	40	Lube	35	381	30.8		.915	17	0.9	W	1.33	2.0			0-.51		0.3	13.7	4.0		.38	SH	

Table E-4. Test results - B.F. Goodrich boom.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
5/5	0930	41							10	2.7	SE					.25-1.27		0	0	∞		1.27	SP	
5/5	0945	42							10	2.7	SE					.25-1.12		0.3	13.7	4.0		1.09	SP	
5/5	1030	43							11	2.7	SE					.15-.25		0.3	2.7	1.5		0	SP	
5/5	1045	44							11	2.2	SE					.25-1.02		0.6	9.1	3.0		0.74	SP	
5/5	1115	45							11	2.2	SE					.25-1.27		0.3	22.9	6.0		1.14	FL	
5/5	1400	46	Lube	37	381	31.5		.915	14	0.9	SE	1.33	2.0			.43-.56		0	0	∞		0.43	SH	
5/5	1530	47	Lube	33	381	31.5		.915	16	0.9	SE	1.32	2.0			.25-.56		0.6	9.1	3.0		0.46	SH	
5/6	1100	48	Lube	33	331	31.2		.915	14	0.4	E	1.32	2.0			.43-.56		0.3	13.7	4.0		0.43	SH	

Table E-4 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec.		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
5/6	1515	49							17	4.5	SE					.25-1.12		0	0	∞		0.84	PL	
5/6	1530	50							17	4.5	SE					.25-.81		0.3	13.7	4.0		0.74	PL	
5/6	1545	51							17	4.5	SE					0 -.25		0.3	2.7	1.5		0	SP	
5/6	1610	52							17	4.5	S					.25-.61		0.6	9.1	3.0		0.53	SP	
5/6	1635	53							17	4.5	S					.25-1.27		0.3	22.9	6.0		0.79	PL	
5/7	0900	54		24	267	29.0		.915	18	0	S	1.32	2.0			0 -.81		0	0	∞		0.61	SH	
5/8	1100	55		28	124	28.8		.915	16	0.4	E	1.14	2.0			0 -.51		0.6	9.1	3.0		0.51	SH	
5/8	1330	56		40	71	28.7		.915	19	4.9	E	1.13	2.0			0 -.71		0.3	13.7	4.0		0.71	SH	

Table E-5. Test results - Slickbar boom.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec. RANGE		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm					HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
5/21	1600	73							32	4.5	W					0 -1.12		0	0	∞		.46	PL	
5/21	1630	74							32	4.5	W					0 -1.12		0	0	∞		.48	PL	
5/21	1645	75							32	4.5	W					0 -.61		0.3	13.7	4.0		.46	PL	
5/21	1725	76							32	4.5	W					0 -.61		0.3	22.9	6.0		.46	PL	
5/21	1740	77							30	3.6	W					0 -.61		0.6	9.1	3.0		.46	PL.	
5/21	1750	78							30	3.6	W					0 -.51		0.3	2.7	1.5		0	SP	
5/22	1030	79	Lube	32	140	31.3	14.4	.899	19	3.58	E	1.32	2.0			0 -.76		0	0	∞		.46	SH	
5/22	1545	80	Lube	37	131	31.5	12.8	.900	21	2.68	E	1.32	2.0			0 -.76		0.6	9.1	3.0		.46	SH	
5/22	1835	81	Lube	37	131	31.5	12.8	.900	22	2.24	E	1.33	2.0			0 -.76		0.3	13.7	4.0		.46	SH	

Table E-5 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec. RANGE		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm					HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
5/22	2000	82							22	2.24	E					0 -1.02		0	0	∞		.61	FL	
5/22	2015	83							22	2.24	E					0 -1.02		0.3	13.7	4.0		.41	FL	
5/23	0920	84							19	0.5	SE					0 -.61		0.3	22.9	6.0		.51	FL	
5/23	1010	85							21	1.3	SE					0 -.61		0.6	9.1	3.0		.41	FL	
5/23	1100	86							21	2.2	E					0 -.61		0.3	2.7	1.5		0	SP	
5/23	1140	87	Lube	27	298	30.7	6.4	.911	21	2.2	E	1.32	2.0			0 -.51		0	0	∞		.33	SH	
5/23	1345	88	Lube	43	142	31.3	6.1	.910	27	2.7	E	1.32	2.0			0 -.51		0.6	9.1	3.0		.33	SH	
5/23	1430	89	Lube	43	142	31.3	6.1	.910	29	2.7	S	1.32	2.0			0 -.51		0.3	13.7	4.0		.33	SH	

Table E-6. Test results - Kepner boom.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY·														
5/19	0945	57							20	1.8	SE					.25-1.27		0	0	∞		1.07	SU	
5/19	1000	58							21	1.8	E					0 -.36		0.3	2.7	1.5		.25	SP	
5/19	1020	59							21	1.8	E					.25-.76		0.3	13.7	4.0		.56	SP	
5/19	1045	60							21	1.8	E					.25-1.02		0.3	22.9	6.0		.91	SU	
5/19	1115	61							21	1.8	E					.25-.71		0.6	9.1	3.0		.56	SP	
5/19	1300	62	Lube	43	97	31.3	14.2	.896	21	1.8	E	1.32	2.0			0 -.97		0	0	∞		.46	SH	
5/19	1430	63	Lube	43	97	31.3	14.2	.896	21	1.8	E	1.40	2.0			0 -.46		0.6	9.1	3.0		.46	SH	
5/19	1530	64	Lube	43	97	31.3	14.2	.896	25	2.7	SE	1.32	2.0			0 -.46		0.3	13.7	4.0		.46	SH	

Table E-6 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec.		WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
5/20	1315	65							24	1.3	S					.25-1.12		0	0	∞		.86	SU	
5/20	1325	66							24	1.8	S					.36-1.12		0.3	13.7	4.0		.91	SU	
5/20	1410	67							24	1.5	SW					0 -.51		0.3	2.7	1.5		0	SP	
5/20	1430	68							24	1.5	SW					0 -1.12		0.3	22.9	6.0		.91	SU	
5/20	1445	69							25	1.5	SW					0 -1.12		0.6	9.1	3.0		.76	SU	
5/20	1430	70	Lube	41	242	30.7	15.0	.905	32	0.9	S	1.34	2.0			0 -.71		0	0	∞		.71	SH	
5/21	0910	71	Lube	28	228	32.0	14.4	.904	23	0.4	SW	1.32	2.0			0 -.71		0.6	9.1	3.0		.71	SH SP	
5/21	1130	72	Lube	28	228	32.0	14.4	.904	24	1.3	S	1.32	2.0			0 -.71		0.3	13.7	4.0		NO	TC	

Table E-7. Test results - Pace oil boom.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
6/2	1645	110							24	2.7	NW					0 - 1.02		0	0	∞		.89	SU	
6/3	0900	112							21	2.2	NW					0 - .89		0.6	9.1	3.0		.74	SP	
6/3	0915	113							21	2.2	NW					0 - .76		0.3	22.9	6.0		.71	SP	
6/2	1740	111	Lube	43	136	32.5	18.2	.910	24	0.5	W	1.32	2.0			0 - 1.02		0	0	∞		.20	SH	
6/3	0930	114	Lube	29	329	32.3	17.2	.908	22	2.2	NW	1.32	2.0			0 - .89		0.6	9.1	3.0		.18	SH SP	

Table E-7 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
6/3	1600	115							23	13.4	NW					0 - 1.02		0	0	∞		.84	SU	
6/4	0930	117							18	4.5	NW					0 - 1.02		0.3	13.7	4.0		.84	SU	
6/4	1530	119							23	4.9	NW					0 - 1.02		0.6	9.1	3.0		.71	SP	
6/4	1745	121							20	4.5	NW					0 - .25		0.3	2.7	1.5		.18	SP	
6/5	0815	122							19	1.3	SE					0 - 1.02		0.3	22.9	6.0		.91	SU	
6/3	1620	116	Lube	38	200	31.9	17.7	.913	24	3.6	E	1.32	2.0			0 - .51		0	0	∞		.30	SH	
6/4	0945	118	Lube	32	411	31.9	18.5	.908	21	4.5	NW	1.32	2.0			0 - .51		0.3	13.7	4.0		.25	SH	
6/4	1515	120	Lube	38	195	32.2	16.1	.908	23	4.5	NW	1.32	2.0			0 - .51		0.6	9.1	3.0		.23	SH	

Table E-8. Test results - Whittaker boom.

			TEST FLUIDS PROPERTI.						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
												CATENARY												
5/27	1015	90							23	2.2	W					.25-1.02		0	0	00		1.02+	NO	
5/27	1040	90R							23	2.2	W					.51-1.27		0	0	00		1.27	PL	
5/27	1100	91							23	2.2	W					.51-1.27		0.3	13.7	4.0		.97	PL	
5/27	1120	91R							23	2.2	W					.51-1.14		0.3	13.7	4.0		.97	PL	
5/27	1140	92							23	2.2	W					.25-.51		0.3	2.7	1.5		0	SP	
5/27	1320	93							23	2.2	W					.25-1.02		0.3	22.9	6.0		.97	PL	
5/27	1340	94							23	2.2	W					.25-1.02		0.6	9.1	3.0		.97	PL	
5/27	1355	95	Lube	43	177	30.5	10.9	.906	28	4.0	W	1.32	2.0			0 -.51		0	0	∞		.25	SH	
5/27	1445	96	Lube	43	177	30.5	10.9	.906	29	4.5	NW	1.32	2.0			0 -.43		0.6	9.1	3.0		.43	SH	
5/27	1730	97	Lube	43	177	30.5	10.9	.906	30	4.5	NW	1.32	2.0			0 -.43		0.3	13.7	4.0		.30	SH	
5/28	1130	98	#2	28	10	26.8	8.8	.855	21	0.4	NW	1.32	2.0			0 -.51		0	0	∞		.20	SH	

Table E-8 (continued).

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE	-	HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
5/29	1130	101							21	0.4	N					0 -1.02		0	0	∞		1.02+	NO	
5/29	1145	102							27	2.2	E					0 -1.02		0.6	9.1	3.0		1.02+	NO	
5/29	1305	103							27	2.7	E					0 -1.02		0.3	22.9	6.0		1.02+	NO	
5/29	1450	106							27	4.5	SE					0 -1.02		0.3	13.7	4.0		1.02+	NO	
6/2	1430	108							24	2.7	NW					0 -1.02		0.3	2.7	1.5		.25	SP	
5/29	1330	104	Lube	39	238	31.5	18.7	.912	27	3.1	E	1.32	2.0			0 -1.02		0	0	∞		.69	SH	
5/30	1010	104R	Lube	39	238	31.5	18.7	.912	24	1.3	SE	1.32	2.0			0 -1.02		0	0	∞		.81	SH	
5/29	1415	105	Lube	39	238	31.5	18.7	.912	27	4.5	SE	1.32	2.0			0 -1.02		0.6	9.1	3.0		.61	SH	
5/30	0925	105R	Lube	39	238	31.5	18.7	.912	24	2.2	SE	1.32	2.0			0 -1.02		0.6	9.1	3.0		.81	SH	
5/29	1500	107	Lube	39	238	31.5	18.7	.912	27	3.6	SE	1.32	2.0			0 -1.02		0.3	13.7	4.0		.51	SH	
6/4	1030	F2	Lube	32	411	31.9	18.5	.908	21	4.5	NW	1.32	2.0			0 -1.02		0.3	2.7	1.5		.20	SP	

Table E-8 (continued).

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3	SLICK THICKNESS mm			TOW SPEED m/sec. RANGE		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
												CATENARY												
5/28	1315	99	#2	28	10	26.8	8.8	.855	24	0.4	SW	1.32	2.0			0 - .51		0.3	13.7	4.0		.20	SH	
5/28	1445	100	#2	28	10	26.8	8.8	.855	26	2.7	NW	1.32	2.0			0 - .51		0.6	9.1	3.0		.36	SH	

APPENDIX F

TEST RESULTS

SKIMMERS

The following appendix includes raw data compiled from individual test runs. The tables include:

- Test identification
- Test fluids' properties
- Ambient conditions
- Oil slick characteristics
- Tow speed
- Wave characteristics
- Performance measurements

Test fluids' properties represent physical characteristics of post-test samples taken from recovery barrels.

Recovery rate is the rate at which the total mixture (oil and water) was recovered.

Table F-1. Test results - Slickbar skimmers with Marlow pump.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% OIL	% WATER
SKIMMER #1																								
5/5	1300	46	Lube	16	1910	33.0		.915	14	0.9	SE	22.0	24.0					0	0	∞		0.98	43.7	56.3
5/5	1345	47	Lube	14	2472	33.0		.915	16	0.9	E	20.0	19.0					0.6	9.1	3.0		5.07	7.0	93.0
5/6	1050	48	Lube	14	2697	32.5		.915	14	0.4	E	20.0	24.0					0.3	13.7	4.0		0.91	35.9	64.1
SKIMMER #2																								
5/20	1430	70	Lube	25	330	31.1		.906	32	0.9	S	24.0	17.0					0	0	∞		3.01	61.9	38.1
5/21	0910	71	Lube	26	274	32.8		.905	23	0.4	SW	17.0	16.0					0.6	9.1	3.0		3.39	53.0	47.0
5/21	1130	72	Lube	20	378	31.6		.901	24	1.3	S	17.0	14.0					0.3	13.7	4.0		3.79	20.4	79.6
SKIMMER #3																								
5/19	1430	63	Lube	20	274	31.5		.895	21	1.8	E	14.0	11.0					0.6	9.1	3.0		5.47	37.5	62.5
5/19	1530	64	Lube	20	272	30.9		.897	25	2.7	SE	14.0	15.0					0.3	13.7	4.0		3.22	68.6	31.4

Table F-1 (continued).

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% OIL	% WATER
												SKIMMER #4												
6/13	1400	8	#2	32	10	34.0		.852	24	3.1	E	0.2	0.8					0	0	∞		6.31	22.2	77.8
6/16	1530	9	#2	32	10	34.0		.852	28	2.2	SE		0.1					0.3	13.7	4.0		1.98	76.1	23.9

Table F-2. Test results - Acme skimmer.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% OIL	% WATER
4/30	1230	29	Lube	14	1697	33.2		.915	11	4.5	E	14.0	15.0					0	0	∞		5.20	27.3	72.7
5/7	1400	54	Lube	25	282	29.5		.915	18	0		2.8	2.0					0	0	∞		1.77	57.1	42.9
5/8	1100	55	Lube	19	303	28.5		.915	16	0.4	E	3.0	0.8					0.6	9.1	3.0		3.49	41.6	58.4
5/8	1330	56	Lube	19	343	29.3		.915	18	4.9	E	0.1	0.5					0.3	13.7	4.0		4.47	56.7	43.3

Table F-3. Test results - B.P. Vikoma skimmer with Spate pump.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10-3	% OIL	% WATER
6/4	1030	118	Lube	26	367	31.9		.910	21	4.5	NW	24.0	22.0					0	0	∞		1.67	99 +	0
6/4	1530	120	Lube	29	556	32.2		.913	23	4.9	NW	28.0						0.6	9.1	3.0		2.27	84.0	16.0
6/2	1430	5	Lube	26	570	31.7		.919	24	2.7	NW	22.0	30.0					0	0	∞		1.05	76.1	23.9
6/4	1445	6	# 2	26	18	28.5		.857	24	2.7	NW	1.0	0.4					0	0	∞		3.03	99 +	0

Table F-4. Test results - Coastal Services skimmer with Spate and Homelite pumps.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% OIL	% WATER
										SPATE PUMP														
5/22	0930	80	Lube	23	327	30.4		.897	19	0.4	SE	18.0	18.0					0.6	9.1	3.0		1.28	81.4	18.6
5/27	1445	1	Lube	21	513	30.5		.908	28	4.0	W	24.0	24.0					0	0	∞		1.31	29.0	71.0
5/31	1445	109	Lube	22	476	31.6		.895	24	0.4	W	24.0	9.0					0	0	∞		1.58	14.3	85.7
5/28	1405	2	#2	21	21	28.7		.870	26	2.7	NW	1.0	9.2					0	0	∞		1.17	6.0	94.0
5/28	1435	3	#2	24	9	28.3		.853	26	2.7	NW	1.0	0.2					0	0	∞		1.13	6.0	94.0
5/28	1450	4	#2	24	10	28.5		.853	26	2.7	NW	1.0	0.3					0	0	∞		1.21	6.0	94.0
										HOMELITE PUMP														
4/28	1500	21	Lube	10	2295	32.4		.915	16	4.5	W	7.0	7.5					0.3	13.7	4.0		0.68	48.6	51.4
4/29	0920	22	Lube	10	1987	38.1		.915	11	5.4	E	8.0	8.5					0.3	22.9	6.0		1.55	46.5	53.5
4/29	1230	23	Lube	10	1679	33.2		.915	11	5.4	E	6.0	9.0					0.6	9.1	3.0		0.72	66.7	33.3
5/22	1030	81	Lube	22	293	30.5		.898	19	0.4	SE	18.0	17.0					0.3	13.7	4.0		1.29	85.3	14.7

Table F-5. Test results - I.M.E. skimmer with Spate and Homelite pumps.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			TEST FLUIDS WATER CONTENT						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	PRE-TEST %	POST TEST %					HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% OIL	% WATER
												HOMELITE PUMP												
4/22	1400	11	Lube	19	908	33.2		.915	12	2.2	SW	60.0	12.0					0.3	13.7	4.0		1.53	46.7	53.3
4/23	1400	17	Lube	4	3258	33.2		.915	15	6.7	SE	14.0	5.5					0	0	∞		1.38	51.5	48.5
4/24	1030	19	Lube	4	2123	33.2		.915	14	4.4	W	5.0	15.0					0.6	9.1	3.0		2.14	49.8	50.2
												SPATE PUMP												
6/3	1700	116A	Lube	22	676	28.8		.919	24	3.6	E	24.0	22.0					0	0	∞		1.22	61.5	38.5
6/3	1745	116B	Lube	22	393	31.6		.905	24	3.6	E	24.0	20.0					0	0	∞		1.04	74.6	25.4

APPENDIX G

TEST PROCEDURES - BOOMS

A step-by-step test procedure for booms is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets and Data Analysis.

MANPOWER ALLOCATIONS

The following allocations of duties were made:

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.

2. Control room operator - operates the traveling bridge, wave generator and bubbler barrier from the Control Tower located at the North end of the tank. He also collects the data for ambient conditions.

3. Fluids dispensing operator - usually a temporary technician who adjusts the flow control valves for the proper flow rate and records the flow rate.

4. Data documentation officer - observes and records failure conditions and modes of failure. Communicates with the test director and photographer on tow speed changes and documentation of performance. Performs the analysis and reduction of all data.

5. Photographer - photographically documents the test runs with 35 mmm color slides, 16 mm color motion pictures, and/or underwater video tape.

6. Chemical analysis officer - takes samples of the test fluid before its distribution and after its recovery for analysis of water content, viscosity, specific gravity and interfacial tension for the test run. In general, analysis of fluids for chemical and physical properties are within his responsibility.

7. Valve operator- usually a temporary technician who operates the pneumatic valve controls for recirculation and distribution of the test fluid.

8. Fluids clean-up team leader - heads up the operation of cleaning the residual test fluid from the water surface in preparation for the next test run.

9. Fluids refurbishment team leader - heads up the operation of removing water (both free and emulsified) and contaminants from the test fluid prior to its reuse. Also, responsible for operating the diatomaceous earth filter unit to maintain tank water purity and clarity.

10. Other temporary aides were positioned as required.

PRE-TEST CHECKLIST

To ensure that all test systems and equipment were maintained and ready for the test day, the following checklist was used prior to the first test run:

1. D.E. filter system operating
2. Chlorine generator operating
3. Air-bubbler barrier system operating
4. Bridge drive system operating
5. Wave generator system operational
6. Test device operational
7. Test instrumentation operational
8. Test fluid ready
9. Test fluid distribution system operational
10. Test support equipment operational
11. Photographic systems ready
12. Test personnel prepared and ready
13. Complete all pre-run data sheets and checklists

TEST SEQUENCE (WITH OIL)

The following test sequence was used for the catenary and diversionary boom tests:

1. Position the traveling bridge and test device for testing (see Figures 8 and 9).
2. Position all test personnel for testing (see Figures 8 and 9).
3. Inform all test personnel of test conditions taken from the Test Matrix.
4. Calibrate the flow rate using the recirculation mode and continue to recirculate while observing oil temperature and pressure drop. Immediately prior to test run, take sample of recirculating oil and record oil temperature.
5. Give three (3) blasts on the air horn to clear the tank decks, alert all test personnel of test run, and start the wave generator, if required.
6. Using either intercom system or walkie-talkies, begin countdown

from five (5) with the Control Room Operator to begin bridge motion at zero (0) with one (1) blast on the air horn.

7. One (1) blast on the air horn initiates the following: start bridge, start oil distribution, and start stopwatches.
8. Control Room Operator informs Test Director of steady state bridge speed.
9. Data Documentation Officer informs Test Director of boom performance and advises him of speed increases and/or decreases. Photographic documentation occurs simultaneously.
10. Oil distribution ceases after 1.3 m^3 (350 gal) is distributed and distribution time is recorded.
11. Define the boom "no oil loss" speed and modes of failure.
12. Test Director begins countdown from five (5) to stop the bridge, the wave generator and the stopwatches.
13. Lower the bridge "skimming plate" to prevent oil from passing under the bridge and to skim all residual oil back to the North end of the tank into the surface containment area.
14. All boom data sheets are completed and the integrated skimmer tests begin if required.
15. Reverse the bridge and test boom to prepare for the next test run.
16. Stability Tests would follow this same procedure without the oil being distributed.

DATA SHEETS

The following data sheets were used for the boom tests:

1. Test Equipment Characteristics
2. Chemistry Laboratory Analysis
3. Flow Rate/Volume Data Sheet
4. Ambient Conditions Data Sheet
5. Boom Test Data Sheet

DATA ANALYSIS

The Data Documentation Officer performs all data analysis and reduction. All data sheets are submitted to him for compilation onto master raw data sheets as shown in Appendix E. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.

APPENDIX H

TEST PROCEDURE - STATIONARY SKIMMERS

A step-by-step test procedure for stationary skimmers is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets, and Data Analysis.

MANPOWER ALLOCATIONS

The following allocations of duties were made:

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.
2. Control room operator - operates the wave generator and collects the data for ambient conditions.
3. Fluids dispensing operator - maintains the oil thickness at 2.54 cm at the beginning of each run. Assists with other duties as needed.
4. Data documentation officer - observes and records oil collection data and keeps a notebook of performance observations. Performs the analysis and reduction of all data.
5. Photographer - documents the test with 35 mm color slides and 16 mm color motion pictures.
6. Chemical analysis officer - samples the test fluid before and after the test run. Samples are analyzed for water content, viscosity, specific gravity and interfacial tension.
7. Test equipment operator - starts the recovery pump and operates the equipment according to manufacturers' recommendations.
8. Fluids refurbishment team leader - heads up the operation of removing water and contaminants from the test fluid prior to its reuse.

PRE-TEST CHECKLIST

To ensure that all test systems and equipment are maintained and ready for the test, the following checklist is used prior to the first test run:

1. D.E. filter system running.
2. Chlorine generator operating.
3. Air-bubbler barrier operating.
4. Wave generator system operational.
5. Test device operational.
6. Test fluid ready.
7. Test support equipment operational.
8. Photographic systems ready.
9. Test personnel prepared and ready.
10. Complete all pre-run data sheets and checklists.

TEST SEQUENCE

The following test sequence was used for the stationary skimmer tests:

1. Establish thickened spill condition of 2.54 cm thick slick.
2. Place skimmer system in operating position for the test run.
3. Establish wave conditions according to the test matrix.
4. Place and maintain the recovery hose in the polyethylene recovery tanks.
5. Start the skimmer system with controls set for optimum recovery conditions.
6. Start the stopwatch when recovered fluid begins discharging into the recovery tanks.
7. Check the recovery rate intermittently and photograph the test run.
8. Terminate test run after either 1.89 m^3 (500 gal) is recovered or 30 minutes of test time elapsed.
9. Measure the total recovered fluid, recovery time and temperature of test fluid.
10. Measure the collected oil after allowing the water to settle out for at least one half hour.
11. Take sample of the oil layer for analysis.
12. Prepare for the next test listed in the test matrix.

DATA SHEETS

The following data sheets were used for the skimmer tests:

1. Test Equipment Characteristics
2. Chemistry Laboratory Analysis
3. Ambient Conditions Data Sheet
4. Skimmer Test Data Sheet

DATA ANALYSIS

The Data Documentation Officer performs all data analysis and reduction.

All data sheets are submitted to him for compilation onto master raw data sheets as shown in Appendix F. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.